IRRIGATION

IN THE UNITED STATES

BY

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The forest and water problems are perhaps the most vital internal questions of the United States.

ROOSEVELT

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To

JOHN WESLEY POWELL

THE PIONEER IN SCIENTIFIC CONQUEST OF THE ARID

LANDS OF THE NATIONAL DOMAIN

There is no one question now before the people of the United States of greater importance than the conservation of the water supply and the reclamation of the arid lands of the West, and their settlement by men who will actually build homes and create communities.

ETHAN ALLEN HITCHCOCK.

Throughout our history the success of the home-maker has been but another name for the upbuilding of the nation.

THEODORE ROOSEVELT.

Stability of national character goes with foothold on the soil.

DAVID STARR JORDAN.

PREFACE.

IRRIGATION as it is related to the utilization of some of the great untouched resources of the United States is here discussed, and especial attention is devoted to the opportunities for making homes upon the vast extent of vacant public lands now waste and desolate. A somewhat elementary and popular description of irrigation and of the devices for obtaining and distributing water is given, including details of interest to persons who are beginning to give attention to the subject. More space is devoted to the crude, but effective, home-made contrivances than to the elaborate or expensive machinery purchased from manufacturers, for the success of irrigation depends most largely upon the rough-and-ready ingenuity of the first settlers in a new country in adapting their ways to the environment.

The writer has been continuously engaged for the last twelve years in conducting investigations of the extent to which the arid regions can be reclaimed by irrigation, ascertaining the cost and capacity of reservoirs, measuring the flow of rivers useful for power, irrigation, and other industrial

purposes, and mapping the artesian or underground waters. The attempt is here made to bring together, in as non-technical a manner as possible, the results of this study and experience.

Acknowledgment is due to the Director of the United States Geological Survey, Hon. Charles D. Walcott, for his interest in the matter and for permission to use illustrations and data from the files of the office, and to numerous friends and coworkers in the Survey who have generously aided in many ways. Especial recognition should be given to Major John Wesley Powell, the former Director, to whose foresight and energy is due the inauguration, in 1888, of the investigation by the Geological Survey of the extent to which the arid lands can be reclaimed by irrigation.

Thanks for material and assistance are given to Mr. Herbert M. Wilson, the author of the "Manual of Irrigation Engineering," of "Irrigation in India," etc.; to Mr. Arthur P. Davis, hydrographer for the Geological Survey and also for the Nicaragua and Isthmian Canal Commissions; to Mr. J. B. Lippincott and to Mr. A. L. Fellows, irrigation experts respectively for California and Colorado; to Mr. George H. Maxwell, of The National Irrigation Association; to Professor F. H. King, author of "Irrigation and Drainage"; to Mr. James D. Schuyler, author of "Reservoirs for Irrigation"; and to various writers on water supply and artesian conditions, particularly to Professor Israel C.

Russell, Mr. N. H. Darton, Professor T. C. Chamberlin, Professor Samuel Fortier, Professor E. C. Murphy, Mr. Frank Leverett, Professor E. H. Barbour, Professor Alfred C. Lane, Professor J. E. Todd, Professor Thomas U. Taylor, and Mr. George Otis Smith, all being connected to a greater or less degree with the investigation of the water resources of the United States.

Mention should also be made of various books which have been consulted: "The Conquest of Arid America," by William E. Smythe; "Irrigation Farming," by Lute Wilcox; "The Nation as a Landowner," by J. D. Whelpley, and pamphlets and reports by C. E. Grunsky, Marsden Manson, Elwood Mead, Clarence T. Johnston, E. J. Wickson, B. C. Buffum, J. C. Ulrich, R. H. Forbes, E. B. Voorhees, and others.

The literature on irrigation is now so extensive that few persons can claim to have more than a general knowledge of it. Free use has been made of all available sources of information, but no attempt has been made to assign credit for any particular item of information or illustration.

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CHAPTER I.

RECLAMATION OF THE PUBLIC LANDS.

Home-making is the aim of this book; the reclamation of places now waste and desolate and the creation there of fruitful farms, each tilled by its owner, is its object. The attainment of this end is sought by directing attention to the resources of our great unutilized domain, in the hope that, through a more complete knowledge of these and the methods of their utilization, vigorous and wise action may supersede the present lax and improvident policy.

One-third of the whole United States, exclusive of Alaska and outlying possessions, consists of vacant public land. One of the greatest economic questions before our people is that relating to the utilization of this vast area, much of which has a rich soil and under good management is capable of sustaining a large population; while, if neglected, there will continue to be only widely separated ranches and nomadic herdsmen. As the control of the vacant public lands is now tending, these areas are not being made available for the creation of the largest number of homes.

This matter is one not merely of local interest to the West, but is of even greater concern to the East, and to all who are dependent upon the manufacturing and transporting interests, as well as to the farmers who supply all of these workers with food. The widening of settlement in the West means a rapidly increasing market for goods manufactured in the East and transported to the West. With more people engaged in making the finished articles and carrying them to the West, there comes a larger and larger demand for agricultural products, especially those raised near the manufacturing centres. In short, the prosperity of the whole country follows the upbuilding of any considerable portion.

The vacant public lands are for the most part desert-like in character, and their utilization can come about only through irrigation, or the artificial application of water to the soil, to supplement the scanty rainfall or to supply its absence. In a wider sense, irrigation is taken to include the whole question of conservation and utilization of water in the development of the arid regions, and to embrace a discussion of features of social and political importance arising from the reclamation of the arid public domain. In the first instance, irrigation is of greatest importance to the farmer who is attempting to raise crops in a country of deficient rainfall. He wishes to produce the most profitable fruits or grains with the least expendi-

THE ISOLATED HOME ON THE WIND-SWEPT UNIRRIGATED PLAIN.

ture of time and energy. For him a discussion of irrigation means a description of the methods of applying water, the amount to be given to various soils and to different crops, and the results obtained by applying or withholding water at various periods of plant life. In the second instance, irrigation is of concern to all citizens of the United States, since they are the great landowners, and as such are interested to see that their lands are put to the best uses; it is their duty, as citizens, to guard the public lands, the heritage of their children, and prevent their falling into the hands of persons who will treat them as speculative commodities.

It is from both these standpoints that the subject is here discussed. It is unquestionably a duty of the highest citizenship to enable a hundred homes of independent farmers to exist, rather than one or two great stock ranches, controlled by non-residents, furnishing employment only to nomadic herders. These alternatives and their results must be borne in mind to appreciate properly the effect of either neglect or forethought upon the future of the country.

The mineral or substance which has the greatest direct influence upon man, his health and industries, is water. Its quality, and especially its quantity, directly affect his occupations. If there is too much, the ground is marshy, malarial, and unfit for cultivation; if too little, the plants valuable for food do not thrive. There is a narrow range

between excess and deficiency, and upon the nice adjustment of the balance between moisture and drought depends the existence of prosperous communities.

Taking the world as a whole, the greater part of the earth's surface is not utilized, even though the climatic conditions as regards heat and cold are favorable for occupation. The outer covering of disintegrated rock and vegetal mould known as the soil is suitable for the support of useful plants, except in the one respect — that of moisture. Most plants require a certain continuous supply of water, neither too much nor too little. In humid climates where the annual rainfall is fifty inches or over, there are enormous areas so thoroughly saturated with water that farm crops are not possible. The creation of homes here is dependent upon ability to remove by drainage the excess of water. In contrast to this there are in the arid region still greater expanses of good soil where the occasional rains are not sufficient to bring food plants to maturity.

The location of the vacant public land is shown on the accompanying diagram (Fig. 1), which gives the outline of the United States from the 97th meridian westerly to the Pacific coast. Texas is excluded, as this state, entering the Union from the condition of an independent republic, retained control of its land. The black areas on the small map indicate the lands which have passed out of

the possession of the general government. In the eastern part it is seen that practically all of the land has been disposed of. White spots appearing in the black areas of western Kansas and Nebraska

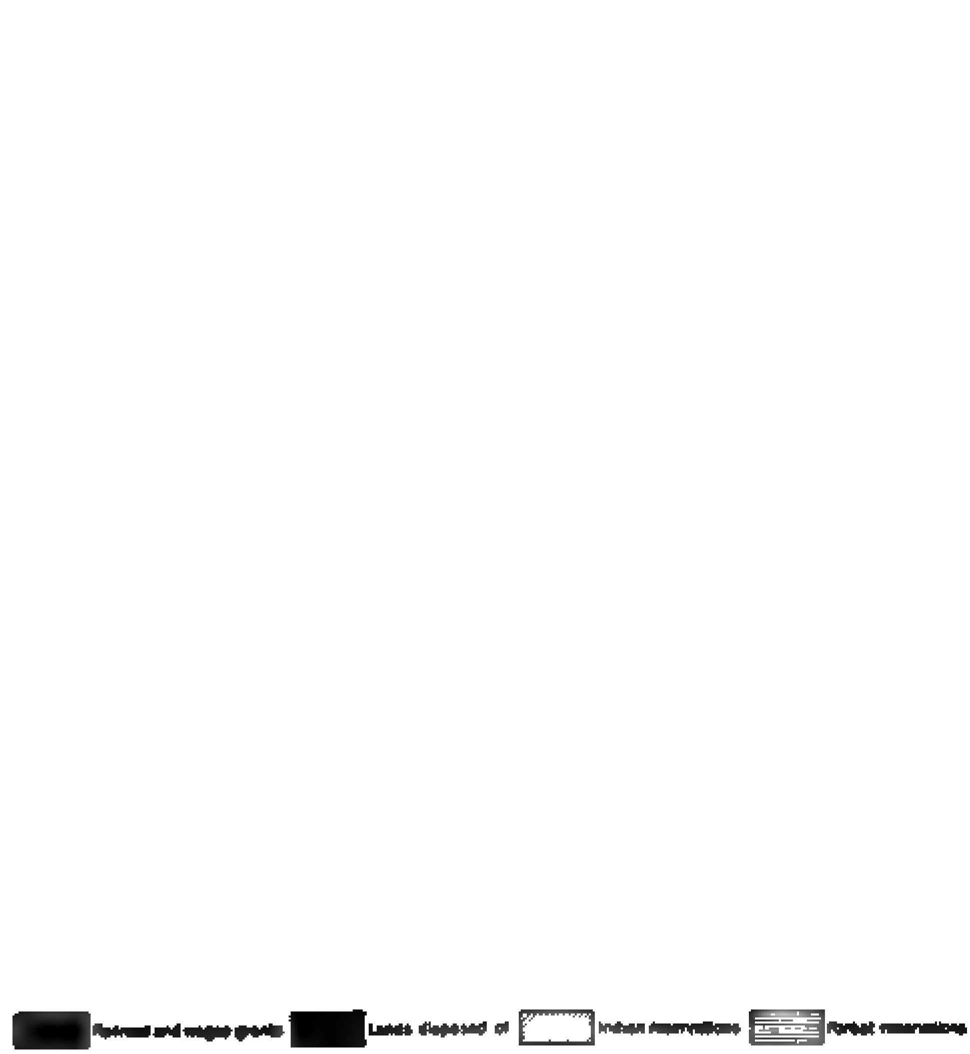


FIG. 1. — Map of vacant public land.

indicate that there are still a few tracts left untouched. Near its centre the greater part of the map is white, indicating that nearly all of the land is under the control of Congress, the black spots

in this area showing, usually in exaggerated form, the relative position of lands taken by farmers or stock men. Near the Pacific coast the area disposed of again increases, including most of the valleys. The area of the land surface of each state and territory and the amount vacant in each, also the extent of land held in forest, Indian, military, and other reservations are shown in the following table.

VACANT AND RESERVED AREAS IN THE WESTERN PUBLIC LAND STATES.

STATE OR TERRITORY.	Total Area.	Vacant.		Reserved.
	Acres.	*Acres.*	Per cent.	*Acres.*
Arizona	72,268,800	48,771,000	67.5	18,285,000
California	99,827,200	42,049,000	42.1	16,064,000
Colorado	66,332,800	39,116,000	59.0	5,694,000
Idaho	53,945,600	42,475,000	78.7	1,747,000
Kansas	52,288,000	1,085,000	2.1	988,000
Montana	92,998,400	65,803,000	70.8	12,348,000
Nebraska	49,177,600	9,927,000	20.2	70,000
Nevada	70,233,600	61,322,000	87.3	5,983,000
New Mexico . . .	78,374,400	55,589,000	70.9	6,385,000
North Dakota . .	44,924,800	16,956,000	37.7	3,370,000
Oklahoma	24,851,200	4,654,000	18.7	7,158,000
Oregon	60,518,400	33,784,000	55.8	5,500,000
South Dakota . .	49,184,000	11,869,000	24.1	12,803,000
Utah	52,601,600	42,516,000	80.8	5,488,000
Washington . . .	42,803,200	11,913,000	27.8	10,765,000
Wyoming	62,448,000	47,657,000	76.3	7,995,000
Total . . .	972,777,600	535,486,000	55.1	120,643,000

THE HOME MADE POSSIBLE BY IRRIGATION.

Stretching across the map are a number of bands made up of lines crossing one another. These indicate the size and position of the great railroad land grants, within which every alternate section has been given as bonus for the construction of transcontinental lines of communication. These are, from north to south: the Northern Pacific, the Union Pacific to Ogden, the Central Pacific from there to California, the Atlantic and Pacific, and the Southern Pacific. In addition to these vast grants of land are seen the narrower wagon-road grants in the state of Oregon. Two classes of reservations are indicated on the map, namely, the lands held for Indians, and those set aside for the preservation of the forests. The locations of these are shown on the map, Fig. 10, p. 34. The fact which it is desired to bring out at this time is the enormous extent of the public land and the way in which it is cut up by grants, reservations, and private holdings.

The public lands are open to entry and settlement under what is known as the Homestead Law, the intent of which is to provide homes especially for that part of the population who are capable of self-support, and who, having little or no capital beyond their labor, are eager to make for themselves homes and to become landowning citizens. It is not the purpose of the land laws to dispose of the lands as rapidly as possible, but on the contrary to serve as an outlet for the energy and labor of

the nation. This object is peculiarly important at times of industrial depression when men seek work in vain, and gladly avail themselves of the opportunities which in the past have been offered on the public domain. The stability of the government has been largely due to the fact that there has always been this outlet for superfluous labor, and opportunities for the making of homes.

Within the last decade, however, a great change has gradually come about, and its effects are only now being noticed. The original intent of the land laws is not being accomplished as far as homesteading is concerned, because the remaining public lands, although of enormous extent as previously stated, are for the most part within the arid region, and crops cannot be produced until a water supply has been obtained sufficient to moisten the soil during the growing time. There is a considerable amount of water which can thus be employed, but the expense of utilizing it is too great for the settler. The localities where water can easily be diverted to the thirsty soil have already been taken up by the pioneers. The larger works necessary to take water to less accessible localities require the investment of considerable sums of money, far beyond the reach of the ordinary settler.

In the old days it was possible for a man with a team and the ordinary farm tools to construct ditches leading from the creeks flowing out of the mountains, and to provide channels by which his

farm could be irrigated. In this way he was able to produce crops on the low lands along the rivers, and to gradually extend the system of water supply even to the adjacent terraces or bench lands. But the later comers find that the small streams are already fringed with farms, and the land lying beyond these, although sometimes better in quality, cannot be reached without incurring great expense.

It is for the interest of the public at large and the nation to have all of these good agricultural lands utilized; and the question arises, Who is to make it possible for the settler to occupy them? This is a question which, if satisfactorily answered, must be by the lawmakers of the nation, and for this purpose they, as well as the thinking public, should be in possession of the facts.

The laws governing the disposal of public lands have been drawn almost wholly with reference to the broad prairies and plains of the Mississippi Valley, where the rainfall is sufficient for the maturing of crops. Under the prevailing system of dividing the land, surveys are made in such a manner as to cut it into blocks as nearly square as possible, lines being run north and south, east and west, at intervals of six miles, enclosing areas of approximately thirty-six square miles, known as townships. Each side of the township is divided into miles, and from these points are run cross lines which subdivide the land into thirty-six sections, each containing one square mile, or 640 acres.

These again are cut into quarter-sections, consisting of 160 acres, and finally into fourths of a quarter-section, consisting of 40 acres and commonly known as forties. The sections are numbered consecutively, beginning at the northeast corner of the township, and continuing westerly, then easterly, and back and forth, ending in Section thirty-six in the southeast corner.

These lines of rectangular survey are run wholly without reference to natural features, such as smaller streams, hills, and valleys. In the well-watered, comparatively level country, such as the Ohio and Mississippi valleys and the Great Plains, this disregard of the natural features is unimportant when compared with the desirability of having simple and easily defined boundaries. Here, where the rainfall is sufficient for the production of crops, practically every quarter-section of the flat or gently rolling country is as good as the next, there being small difference of soil or of surface slopes. Each farmer taking up a quarter-section is independent as regards his method of cultivation, and can conduct his operations in such manner as his experience may dictate. In the vast arid regions, however, where lie the greater part of the remaining public lands, the value of the farm depends almost wholly upon the question of water supply. The accessibility and permanence of this far outweigh all other considerations. The interests of each farmer are closely allied with those of his neighbor, as all must

depend upon streams or sources of supply used in common. Here independence must give way to coöperation; and while adjoining lands may be equally good as regards soil, their value may be far different, because water can be taken to one tract while for the other none can be had. The man who controls the water virtually owns everything of value. This fact has not been sufficiently recognized in laws governing the disposal of the public lands, and in many localities water monopoly has resulted from the neglect of needed safeguards. Title to a few hundred acres along watercourses has virtually given possession to thousands of acres of other land, preventing settlers from acquiring these because they are shut off from access to the springs or streams. In short, the creation of hundreds of homes has been prevented by neglecting to protect the right to the use of the scanty water supply.

Without going into details, it is sufficient to state that the rectangular system of division of the public lands, while one of the most beneficial measures leading to the settlement of the Ohio and Mississippi valleys, has been found to be detrimental to the best growth of the western two-fifths of the United States. This has arisen from lack of knowledge by the public, the owners of the land, as to the part which irrigation plays in the utilization of the resources of the West. Attention has been concentrated upon land titles, and great care has been exercised in the survey and marking of boun-

daries and in recording the patents or deeds; while the water, which alone gives value, has hardly been considered, and the rights to its use have often been left to be adjusted largely by local or temporary expedients. It would have been far better, if one or the other of these items must have been neglected, to have given first thought to the water and secondary consideration to the land, subdividing this with reference more to the possibility of obtaining water than for convenience of survey.

To remedy this and bring about such a condition that the remaining public lands may furnish the greatest possible number of homes, is an object worthy the sustained effort of enlightened and patriotic citizens. To assemble the facts upon which intelligent action can be based is a task to which the best efforts of aspiring students or investigators may be directed. These facts pertain first of all to the water supply and its limitations, since, in a country where arid land is in excess, the agricultural area is limited by the available water.

CHAPTER II.

THE ARID REGIONS.

THE arid regions of the United States include about two-fifths of its entire area, and extend from about the middle of the continent west nearly to the Pacific Ocean. There are no sharply marked lines or divisions between the arid and humid areas, but intermediate, especially near the centre of the United States, is a broad belt neither distinctly arid nor humid, which has sometimes been called the subhumid, or again the semiarid, region. This belt extends over South and North Dakota, western Nebraska, and western Kansas into Oklahoma and the "pan handle" of Texas. In some years of excessive moisture the subhumid region creeps up toward the foothills of the Rocky Mountains, while, during the dry years, the greater part of the plains region west of the Missouri becomes semiarid.

In a general way arid regions are taken as including those of twenty or less inches of average annual rainfall; thus, the arid regions of the United States are but a portion of those of

North America, which embraces a considerable part of Mexico on the south and of Canada on the north. The relative extent of these regions of humidity and of aridity can best be shown by a small diagram (Fig. 2).

Modern civilization has developed largely in humid regions, and we have thus come to regard

FIG. 2. — Map of humid, semiarid, and arid regions of the United States.

aridity as something exceptional; as a matter of fact, however, a great part of the countries of the Old World have less than twenty inches of annual rainfall, and according to our ideas must be considered as arid. The civilization of former times grew up in these arid regions, and we cannot fully appreciate the writings of the ancients and the true meaning of many familiar phrases handed down

RESULTS OF ATTEMPTS TO MAKE HOMES ON THE PUBLIC LANDS WITHOUT FIRST PROVIDING METHODS OF IRRIGATION

to us without bearing in mind that theirs was an arid region, where agriculture was successful only through irrigation.

The small map (Fig. 3) illustrates the great extent of aridity, and shows that the Mediterranean countries, including Egypt, the seat of ancient civilization, are for the most part arid and

FIG. 3.—Map of humid and arid regions of the world [the humid indicated by the black areas].

desert-like in character. The dense foliage of the forests of eastern United States and of Europe and the verdant covering of turf so common in our modern towns and villages were practically unknown to the races who produced the sacred books of the East; and their constant reference to the life-giving qualities of water furnishes innumerable instances of the high esteem in which this was held.

PRECIPITATION.

Aridity, or rather the unequal distribution of moisture, is largely the result of topography, or inequalities of land surface. If the earth were perfectly flat, it is probable that the winds, meeting with no obstructions, would distribute the rains with considerable uniformity in broad bands approximately parallel to the equator; but the relatively thin layer of dense atmosphere surrounding the globe is disturbed in its uniform flow by the lofty mountain masses which traverse the continents. The atmosphere surrounding the earth extends outward for many miles, but it is the layer, a mile or two in thickness, resting immediately upon the surface, and relatively dense, within which occur the changes or disturbances that make up what we know as "weather." The movements of the air above this thin layer concern us little; but the behavior of the clouds and the winds near the surface of the ground brings success or failure to the farmer, and affects more or less directly other industries, and even health.

Taking the United States as a whole, the general atmospheric movement is from west to east; the moisture-laden winds from the Pacific, encountering the mountain masses which extend along or parallel to the coast, are forced upward and cooled, depositing much of their moisture, especially in the winter season. They then pass easterly as dry

winds, leaving the broad plains east of the Sierra Nevada parched and sterile. In the summer, however, when the mountains have become relatively warm, winds from the Pacific pass over them without leaving their moisture, and the result is the summer drought characteristic of the Pacific coast. Passing onward, the winds not deprived of humidity give up from time to time some of the precious fluid, and thus in the interior there are the occasional summer rains which tend to make amends for the deficient precipitation of the winter season.

East of the Sierra Nevada and Coast ranges, and of the plains and deserts at their base, are scattered irregular mountain ranges, and the great Cordillera or Rocky Mountain system, whose high summits intercept some of the rain-bearing winds, and these for the most part are well watered, while the low lands are parched with drought. From the east face of the Rocky Mountains the High Plains stretch out through the Mississippi Valley, dropping gradually in altitude to the rolling plains and prairies.

The average monthly precipitation is illustrated by the accompanying diagram (Fig. 4), which brings out graphically the contrast between the distribution of precipitation on the western coast and in the interior. The height of each of the small black columns represents the average amount of rain for the corresponding month. Taking, for

example, San Francisco, it is seen that the rain for January averages more than four inches, the amount decreasing during February, March, and April, and becoming less than one-half an inch

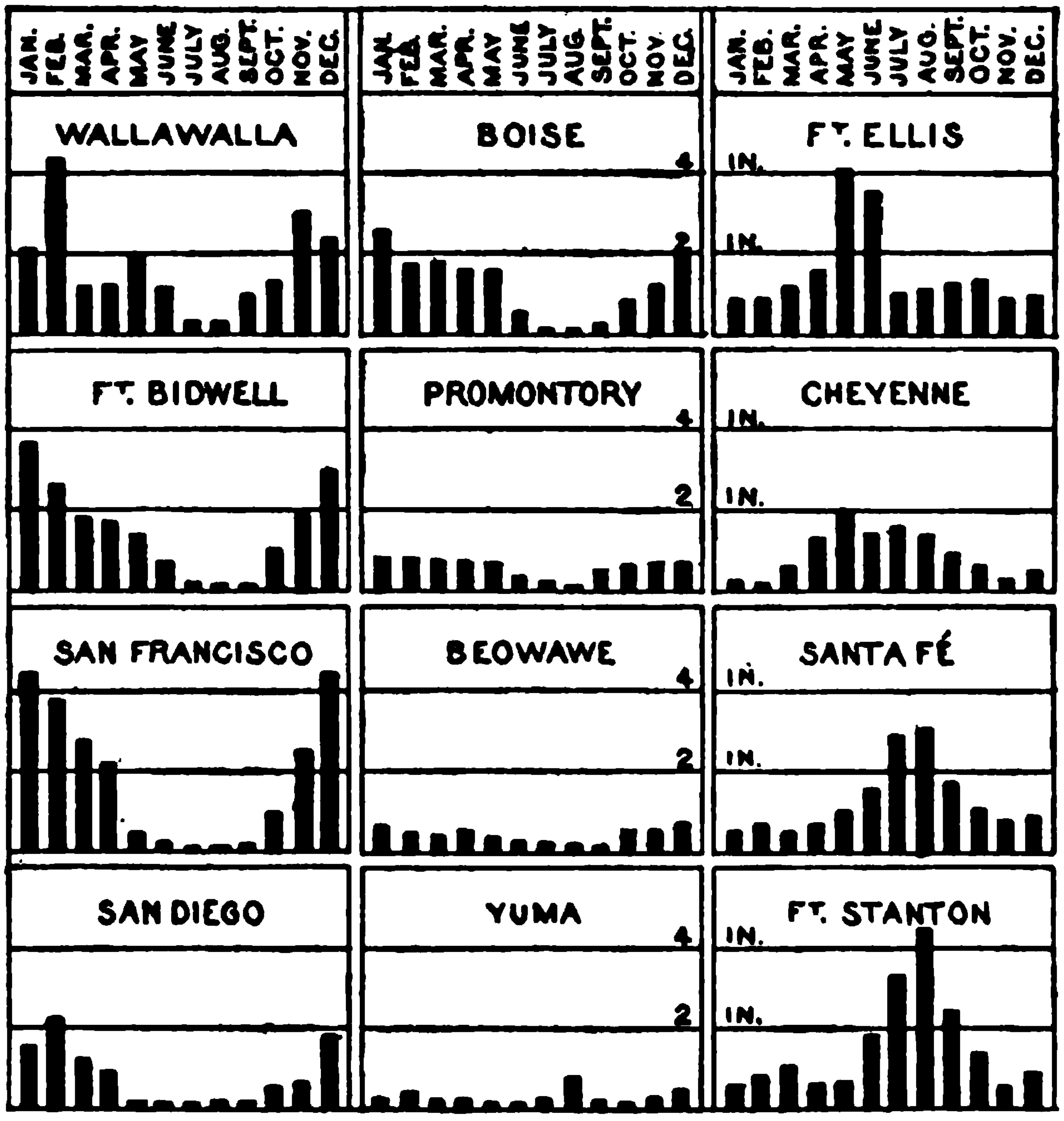


FIG. 4. — Mean monthly precipitation at twelve localities in western United States.

in May. In June, July, August, and September there is practically a drought, with sudden increase in amount of precipitation in October, November, and December. In contrast to this is the distribu-

tion of rainfall at Santa Fé, where the spring and winter months have comparatively little rainfall, the greatest amount occurring in July and August. Thus it may happen that, although there is more than twenty inches of rainfall each year at points near the Pacific coast, yet irrigation is necessary during the latter part of the crop season, and especially in the summer; while in other localities having less annual rainfall, but with heavy summer precipitation, the artificial application of water is not needed.

This diagram (Fig. 4) illustrates the actual amount of rain and snow fall in an average year at the various points, and shows that there is a wide difference in the quantity received. In some localities there is about the same amount of rainfall each month, and in others there are summer droughts. This matter is brought out more clearly when we compare, not the actual amount of rain each month, but the proportion which this bears to the total precipitation of the year; that is to say, calling the average annual rainfall for each locality 100, the amount for one month, if the rain fell equally throughout the year, would be 8.33, or $\frac{1}{12}$ of the whole, whether the total amount for the year be 15 inches or 50 inches. By thus obtaining monthly percentages, it is possible to compare the character of the rainfall in different parts of the United States. This is done in the following diagram (Fig. 5), which shows, not the actual

depth of rain, but the percentage for each month in four localities, namely: Buffalo, New York;

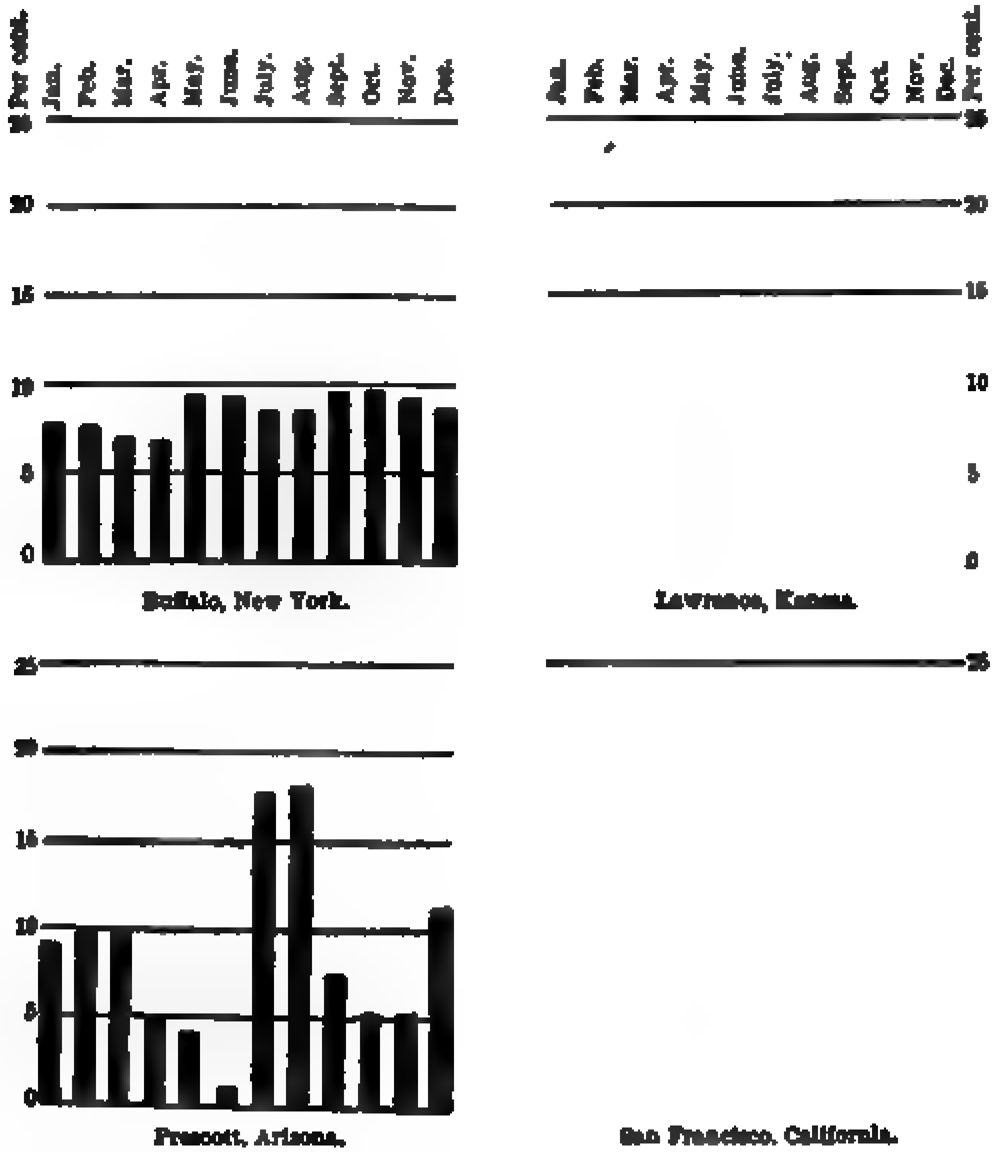


FIG. 5. — Types of monthly distribution of precipitation, shown by percentages of average annual rainfall.

Lawrence, Kansas; Prescott, Arizona; and San Francisco, California.

In the case of Buffalo it is seen that the average

rainfall for each month ranges from 7 to 10 per cent, never quite reaching the latter, and thus showing that throughout the year very nearly the same amount of precipitation occurs. Comparing this with Prescott, Arizona, it is seen that the average precipitation in one month, June, is less than 2 per cent, while in the next two months it is raised to over 17 per cent, showing the great irregularity and the necessity of providing against a June drought.

The diagrams for Lawrence, Kansas, and for San Francisco, California, are seen to supplement each other, although in San Francisco the extremes are far greater than in Kansas. There is no month in the latter state when the rain averages less than 4 per cent of the total, while in California, during July and August, the precipitation is practically nothing.

These diagrams, being illustrative of averages of a considerable number of years, exhibit a regularity which does not occur in any one year. The monthly rainfall, while tending to follow in the long run a certain law, is from season to season extremely erratic, — the amount in one year being sometimes one-half as much or twice as great as that of another. To illustrate these fluctuations the accompanying diagram (Fig. 6) is given, showing the variation in annual rainfall at three points near the centre of the arid regions, viz., Salt Lake City, Utah, Fort Wingate, and

Santa Fé, New Mexico. The average annual rainfall, indicated by the heavy horizontal line, is for Salt Lake City a little over 15 inches. In 1880, however, the amount was 11 inches, and in 1885 nearly 22 inches, fluctuating, as shown on the diagram, between 10 and 22 inches. Similar differences can be seen in the diagrams for Fort Wingate and Santa Fé. It is to be noted, however, that the years of excess and deficiency are not

FIG. 6.— Variation in annual rainfall at points in the arid region.

RESULTS ATTAINED BY IRRIGATION.

coincident even in the localities not so very far apart.

When deficiency occurs, the effects of the aridity are notably increased, and an exceptionally large amount of water is needed to supply the lack of rain. These same fluctuations occur in humid climates, but their effects are not so marked. For example, in a country like that of the Atlantic seaboard, where the precipitation averages 50 inches, a deficiency of 10 inches during the year may not have a noticeable effect upon the crops and industrial conditions, but in a country of 20 inches of annual rainfall a deficiency of 10 inches may result in the disappearance of rivers and the destruction of the scanty vegetation, so valuable in cattle and sheep industries.

The amount of precipitation on the surface of the country, although varying greatly from season to season and from year to year, has been found to have a certain stability when looked at in a large way. That is to say, although for a series of years the rainfall may apparently have been increasing or diminishing, yet, taking a long record, as for example one hundred years, it has been found that the average for the first quarter or third of this is practically the same as that for the last third or quarter. In short, it has not been possible to detect any progressive increase or diminution in the amount of precipitation when records extending over thirty or forty years are had.

FIG. 7. — Map of mean annual rainfall.

FIG. 8. — Map of mean annual run-off.

The average or what is termed the normal precipitation for each part of the country can be computed. Departures from this normal may be in one year or another very great, and for a series of years the rainfall may be above or below the normal; nevertheless, the weather conditions seem to swing back, no matter how far they have swayed. The climate may be regarded as fixed, although the weather changes widely and rapidly.

It is because climate has certain fixed relations to localities, that it becomes possible to make maps showing the general distribution of precipitation. The accompanying map (Fig. 7) gives the distribution of rainfall, including melted snow, over the United States. It indicates that in the East, along the Appalachian region and near the coast, there is a heavy rainfall, the amount decreasing inland, and increasing again very rapidly along the Pacific coast. The points of greatest rainfall are in northwestern Washington near Puget Sound, and at the opposite extreme of the country, near the Gulf and Atlantic coast.

The above-described map shows the depth of water which falls upon the land. If this did not flow off during the year, but all stood where it fell, the ground would be covered with water from an inch or two in depth in the arid region up to five or six feet, or even more, on the mountains and along parts of the seacoast. Some of this water, however, sinks into the soil or evaporates, and the

remainder flows off, forming streams. In the present discussion we are particularly concerned with that portion which runs off on the surface, and at this place a companion map (Fig. 8) is introduced to show the quantity of run-off, in comparison with the rainfall. This indicates that where the rain is heaviest the run-off is largest, while in localities where the rain is very light there may be no run-off and perennial streams do not exist. These matters are more fully discussed on page 58, but it should be noted that where there is the greatest rainfall, there is also the largest proportion of this — 50 per cent or more — flowing in the stream; while where the rainfall is least, only 1 or 2 per cent, or even none, goes to form rivers.

FORESTS.

The mistaken conception is sometimes held by citizens of the humid East that aridity implies desert conditions, the absence of vegetation, and the existence of naked rocks and sand glistening in the brilliant sunshine. On the contrary, the area of land which should be classed as desert is relatively small. West of the Great Salt Lake is a desert-like plain of sand and alkali, almost destitute of vegetation, where a few thorny or woody plants are to be found at intervals. Also, in southern California, west of the Colorado River, is the Salton Desert, embracing the bottom of an ancient arm of the Gulf of California, the land surface

being in some places three hundred feet below sea level, but shut off from the tides by the bars and ridges of mud brought down by the river. It is estimated that there are 70,000,000 acres of such desert in the United States out of the entire area of 973,000,000 acres comprising the western public land states and territories, or about 7 per cent of their land surface. The remainder of the arid regions, exclusive of these deserts, is covered with a more or less scanty vegetation of some value to mankind.

In this connection it is desirable to emphasize the fact that in the arid regions of the United States there are no desert conditions comparable in character and extent with those of Africa. There are all gradations of aridity, these differing for the same locality in successive years, owing to fluctuations in the amount of rainfall. In the somewhat arbitrary classifications just adopted, the assumption has been made that lands may be considered as desert where for a number of years in succession grazing is impossible. There may be seasons at rare intervals when the explorer or surveyor can cross even these areas and find occasional water and forage plants.

The higher mountain slopes and mesas whose abrupt rise forces upward the winds, and compels them to deposit moisture, have, as a consequence of the increased precipitation, a covering of trees. These are often scattered, but in many localities

they form dense and valuable forests. Within the arid and semiarid portions of the Western states it is estimated that nearly 120,000,000 acres are covered with woodland, the individual trees, though scattered, having value for firewood, fence posts, and other purposes essential to the success of the pioneers and farmers. In addition, however, over 75,000,000 acres are covered with heavy forests, having commercial value for timber and furnishing logs for sawmills.

The aggregate of the area of desert, woodland, and forest forms a little over one-third of the extent of the arid and semiarid regions; the remainder, estimated at 470,000,000 acres, is grazing land. Thus, so far as area is concerned, it is evident that the grazing industry — the raising of range stock, cattle, horses, sheep, and goats is, and probably always will be, the great industry. When values are considered, however, there is another point of view.

The open range of the arid regions is generally stated to be capable of supporting a cow for every twenty or thirty acres; the same land, when watered and put in alfalfa, will frequently feed ten times as many cattle, or in orchards, with favorable climate, will support a family of three, or even five persons. The open range may have a value of 50 cents an acre, while under irrigation the selling price may rise to $50 per acre, or even $500 per acre when in orchards. Thus the value of the lands is

directly reversed as regards acreage, the grazing land having the greatest extent, and the irrigated land the least, with the maximum value per acre.

The forests of the arid region not only mark the greatest rainfall, but also indicate the locality from which come the principal streams. The head waters of nearly all of the rivers which give value to the lands are within forested regions (Pl. V.) It is commonly known that the forests to a certain extent protect, or even regulate, the flow of these streams, and it has been urged that the largest and best development of the country requires the conservation of the forests along the head waters.

Forest conservation is practicable, when joined with a proper cutting of the timber. Experience has shown that the removing of the mature or ripe trees, such as are best adapted for lumber, may improve the general conditions of the forests. In some of the wooded areas of the West the proportion of trees which have passed maturity and are dying or dead is as high as 40 per cent. It is clear that such trees should be removed before they have lost their value and have become a source of danger to the younger growth. From the commercial standpoint trees have first value for lumber. Fortunately the proper use of the forests in producing lumber is not antagonistic to their preservation and to the perpetuation of favorable conditions of water supply.

A. FORESTS PARTLY DESTROYED (THE DRAINAGE FROM THIS IRRIGATING THE FIELDS SHOWN BELOW).

B. CULTIVATED FIELDS RECEIVING WATER FROM THE PARTLY FORESTED MOUNTAINS.

Public sentiment has been aroused to such an extent that steps have already been taken to preserve some of the forests of the head water streams of the West, primarily for the beneficial influence the leafy cover may have upon the river flow. The national government has set aside over 47,000,000 acres of the forests and adjacent woodlands, and efforts are being made to preserve all the remaining large bodies of public forests thus situated. This first step is being followed by an administration which will preserve the forests from their great enemy, fire, and will ensure a businesslike treatment of them, under which they will yield a revenue sufficient to pay the cost of patrolling and protecting them. The preparation and execution of systematic plans such as those made for the public forests in other parts of the world will make it possible to protect the head waters without cost to the tax-payer.

The accompanying small map (Fig. 9) exhibits the general distribution of the forests of the West, dark spots marking the mountains or highlands. On this map the black portions indicate the relative position of the areas upon which trees of commercial value are growing, or have recently grown; the areas surrounded by an irregular line indicate the wooded localities and lower mountains upon which are scattered trees whose size or condition is such that they are not suitable for lumber, although they have great value to the settler and

farmer in the way of furnishing cheap fuel and material for fence posts and for building cabins,

FIG. 9. — Forests and woodlands of the West.

corrals, and shelter for cattle. Much of the open woodland has been wisely included in forest res-

ervations, because under efficient protection the more valuable trees will thrive.

The forest reserves already created do not by any means embrace all of the public lands covered with valuable trees, but each has been set aside for some specific purpose, —particularly with reference to the protection of the head waters of streams used in irrigation. The relative location of these forest reserves is shown by Fig. 10, on page 34.

On this map are shown not only the forest reservations, but also the lands still held for the use of various Indian tribes, some of these lands including wooded areas. There are also shown the Yellowstone, Rainier, and Yosemite National Parks, which, although not forest reservations, are of the same general character. It is to be noted that the Indian reservations, which formerly embraced almost the entire West, have now shrunk to a small percentage of the vast country, and are steadily diminishing in area, while the forest reserves are being enlarged. The lands are not being entirely taken away from the Indians, but as farms are allotted in severalty to the heads of Indian families, the reservations are gradually diminished, and the lands in excess of those specifically allotted are sold or thrown open to homestead entry by the whites. In a few cases the wooded lands formerly embraced in the Indian reservations have been made into forest reserves.

The care and protection of the forest reservations, while still remaining in the hands of the

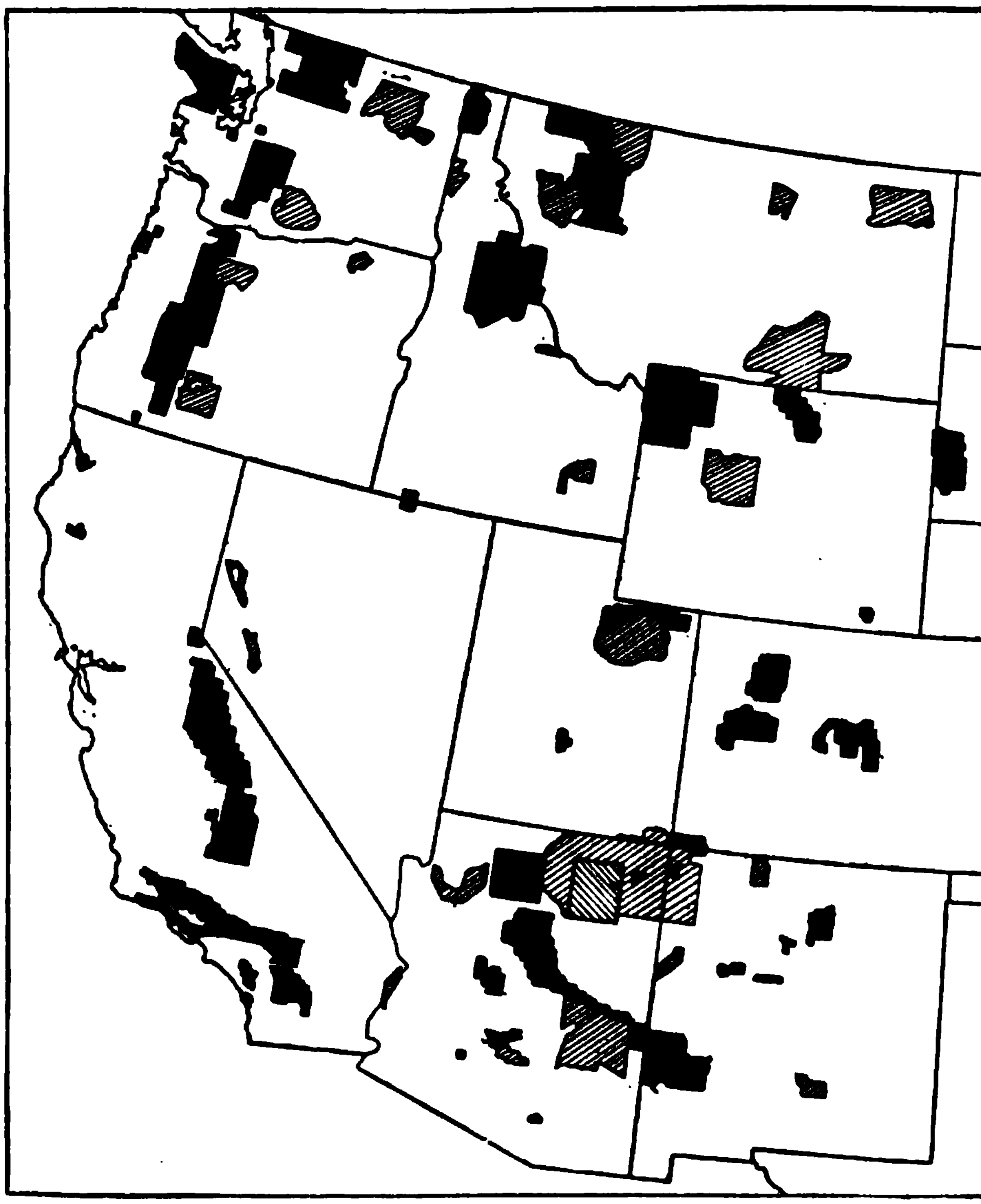


FIG. 10. — Relative position of the forest and Indian reservations. [The forest reservations are shown in solid black.]

national government, has not as yet been placed upon a wholly satisfactory basis. Three bureaus of the government are closely concerned with the

forest reservations. To the General Land Office of the Department of the Interior has been intrusted the guarding and patrolling of the reservations. The survey of the regions within and adjacent to the reserves has been intrusted to the Geological Survey, and detailed topographic maps are being prepared, showing all elevations of the surface, the streams and their catchment areas, the extent of burns resulting from fires, the amount of cutting, and the location of roads, trails, houses, or cabins. Upon the topographic base thus prepared are also shown, by appropriate colors, the general character and commercial value of the standing timber.

Following the mapping of the forest reserves by the Geological Survey comes the systematic examination and preparation of working plans by the Bureau of Forestry of the Department of Agriculture. This bureau, which is working in close cooperation with the Geological Survey, examines the forests with great detail in respect to the particular species of trees, their characteristics and distribution, in order to obtain facts upon which to base working plans — that is, recommendations or outlines of methods to be pursued in cutting or removing certain sizes and grades of timber so as to yield the largest returns and to produce the least injury, or rather the greatest benefit, to the forests, to perpetuate desirable species, and to minimize losses by fire. In this a system has been followed

which has been adopted by some of the large timber owners of the country. By an efficient protection from fire and by following carefully considered working plans, it is possible to enlarge the wooded areas upon the head waters of streams of the arid West, and to increase the beneficial effect, in regulating the flow of the streams upon which the irrigators depend.

GRAZING LANDS.

By far the greater portion of the arid West consists of open grazing lands. These vary in their covering of forage plants from the extremely scanty vegetation of the deserts up to the thick turf which is to be found within the mountain parks. The broad sandy deserts occasionally receive a downpour from the local storms or cloud-bursts, and there springs up at once a scanty herbage, which, though apparently dry and woody, is nutritious and is eagerly sought by the cattle. On the less arid plains there are to be found every year a number of grasses and smaller plants or shrubs, which, drying under the intense heat, become in effect naturally cured hay, and which, though sparsely distributed, thus furnish sustenance for horses, cattle, and sheep.

As summer approaches and the heat upon the deserts and plains becomes intolerable, the herds and flocks gradually move up into the mountains, and find excellent grazing upon the broad slopes

and open spaces within the forested areas; thus a considerable part of the land shown on the small map (Fig. 9) as wooded and forested is also of value for grazing. The interests of the cattle owner, and especially the sheep owner, and of the forester are sometimes at variance, since the cattle, and more particularly the sheep, when the country has been overgrazed, browse upon the young herbage and prevent the growth of small trees; so it is often important to exclude sheep, and even cattle, from the forests in order that the trees may reproduce themselves. The extension of forest reserves has been frequently opposed by the sheep and cattle interests, and the administration of the reserves has been hampered by the demand for free grazing upon the public lands, but this opposition has now ceased.

The sheep industry is one of the most important of the arid regions, and the profits are large, so that from a commercial standpoint it is highly important that the grazing lands extend as widely as possible, even into the forest reserves. It is not good public policy to prevent the growth of wool valued at $10 in order to encourage trees which are worth only $1. It is possible, however, to prepare working plans for the forests which, while preventing overgrazing, will permit the use of the forests as a summer range with a minimum amount of injury to the young growth. A general plan has recently been adopted, which it is hoped will ulti-

mately satisfy the irrigators on the one hand, who are concerned in protecting their water supply, and the sheep owners on the other, who demand that their flocks shall graze wherever young plants can be found.

Forest protection and sheep grazing are not wholly incompatible, for there are certain forested areas where sheep have been and can be allowed to run without serious damage. The exclusion of sheep from the forest reserves should, where necessary, be brought about gradually, so as not to injure this important industry, and the conditions of each locality must be carefully considered before sheep and cattle are either excluded or permitted to graze. The tendency undoubtedly will be to restrict the wide range of the sheep and to bring the industry to the conditions prevailing in older, settled communities, where the sheep are fed through a considerable portion of the year upon improved pastures, or with forage raised by irrigation.

The approximate location and extent of the open or free grazing land are shown in the accompanying map (Fig. 11), the crossed lines indicating the lands where, for the most part, sheep, cattle, and horses graze freely. Some of this is in private ownership, particularly in western Nebraska and Kansas. Texas has been excluded, as the state has sold or leased nearly all of its grazing lands to large cattle owners and the range land is nearly all enclosed by fences. The scale of the map is too

small to exhibit deserts and mountain tops where no forage plants are found. The sketch emphasizes the fact that throughout nearly one-half of

FIG. 11.—Approximate location and extent of the open range.

the United States grazing is the principal industry. Any plan of reclamation and utilization of the vast arid areas must take cognizance of this fact and be shaped accordingly.

Irrigation may be regarded from one standpoint

as an outgrowth or later development of the grazing industry, especially in the more northern part of the arid region. In the early days the sheep and cattle on the open ranges at the approach of cold weather were brought into the lower valleys or sought natural shelter. During severe winters the losses were very large, occasionally one-half of the stock dying during long-continued or extremely stormy weather. With the increase in the business and the overstocking of the ranges, the necessity of providing winter feed for the young or less vigorous animals became more evident, and at the home ranches small areas began to be irrigated in order to provide forage for the winter.

This process has continued to a greater and greater extent, until a balance has been reached between the available summer range and the winter food supply raised by irrigation; that is to say, a cattle owner can maintain as many animals as he can feed for two or three months with forage raised by irrigation, provided he can obtain sufficient range. If, however, his summer range is limited or is partly injured by the incursions of sheep, he may find it economical to reduce the amount of feed raised by artificial watering.

The tendency in the stock-raising business is toward an increase of small owners and decrease of great herds and flocks, owing to the competition for summer range and the necessity for providing an increased amount of winter feed. There is a

gradual evolution from stock raising toward what is sometimes known as stock farming; that is, the owner of a relatively small herd is tempted to put his irrigated land into other crops besides forage, or to raise an additional amount for sale in local markets. Thus, in the stock-raising districts there is a gradual development toward intensive farming.

Nearly every settler upon the public domain, even though intending ultimately to raise the ordinary farm crops and fruits, requires for a time a certain amount of grazing land. He must have a few draft animals and dairy cows, and, as a rule, finds it profitable to own a small herd of cattle or a band of sheep. He desires and needs the use of the public land in his vicinity, in order that he may herd his cattle near his home and bring them in each day or at frequent intervals.

Under existing law the settler who is making a home has no legal claim or right to the use of this public land other than the right possessed by every citizen of the country. Thus, there frequently occur acts which seem to the settler to be grossly unjust, in that cattle or sheep belonging to some non-resident individual, or to a wealthy corporation, may come upon the land in his vicinity and destroy all of the nutritious vegetation, leaving his own cattle to starve. Since the settler is trying to make a home and is paying taxes for the maintenance of law and order, he feels that he has a superior right to the use of the unoccupied land, at least

until the land is wanted for homes by other settlers, or until he is in position to raise by irrigation sufficient forage for his cattle. Thus the settler is often at war with the cattle and sheep owners, and many areas which might have been utilized for homes have been kept vacant through fear of depredations by the cattlemen or even as the result of open violence.

On the free range there are also controversies between rival live-stock owners, and particularly between the sheep owners and the cattlemen. The two kinds of animals cannot graze on the same area, and, as a rule, a band of sheep will render the range unfit for cattle and will drive the latter out. With the growth of the wool industry, the range devoted to cattle is being encroached upon, and many of the owners are disposing of their herds and going into the sheep business, finding it possible to make a living on the public lands by sheep grazing when not successful with cattle.

In many localities there has come about what may be termed an armed neutrality among the various interests concerned with the use of the public land. The settler and irrigator, having obtained a foothold, has been able by combining with his fellows, and by show of force at times, to secure for himself the use of certain pieces of public land for grazing. The cattle companies and larger owners have, as a rule, found it good policy not to encroach upon the settlers who are already

established, and have combined with these men to exclude sheep from the cattle range used by all in common. The sheep owners, after various conflicts and conferences, have agreed to abide within certain other ranges, and for a time at least peace has been assured and all have been fairly content.

The condition just noted is an unstable one, likely to be upset at any moment by the gradually increasing herds of one or another of the parties to the mutual understanding, or by erratic bands of sheep. For example, by tacit consent a certain mountainous or hilly area may have been set aside for cattle grazing for the benefit of the inhabitants of a portion of a county. It has frequently happened that the owner of large bands of sheep in another state, learning that the grazing is good in this area, sends great bands (Pl. VI, *B*) aggregating fifty thousand or one hundred thousand sheep through this part of the country, travelling toward the mountains or market. Such hordes of sheep, progressing slowly, literally destroy all edible vegetation, devastate and ruin the land, and completely upset all local customs and privileges. Occasionally an inundation of this kind is resisted by force, and from time to time local newspapers have a brief item to the effect that an unknown sheep herder was found dead in a remote spot, or that bands of sheep have been dispersed or driven over cliffs by unknown persons.

With the uncertain conditions surrounding the use of the public lands, it is a natural consequence that practically all the farmers and irrigators of the arid region, as well as the stockmen, ask that there be accorded the grazing lands some definite treatment by which, pending complete or final settlement, temporary rights may be had to the use of the forage. It is highly essential for all concerned to be able to enjoy undisturbed possession from year to year of certain lands to be used for grazing purposes. For such a license the owners of the sheep, cattle, or horses are willing to pay a suitable compensation.

The necessity of restricting grazing on portions of the public domain has become apparent, particularly in Arizona, where in the southern part of the territory there are areas upon which the industry has practically exterminated itself. In one locality in the vicinity of Tucson, where formerly 20,000 head of cattle ranged, only a few hundred can now find subsistence. This is due to the fact that some years ago, when there was a decline in the value of cattle, the shipments were reduced and the herds multiplied. Then came a season when the drought was severe, the feed became scanty, and the starving cattle ate practically every living shrub, digging down even to the roots, so that plants and cattle perished together. The few cattle remaining have been sufficient to prevent the forage plants from spreading again, but where small areas have been

A. YOUNG FOREST GROWTH SUCCEEDING A FIRE.

B. SHEEP GRAZING IN THE FORESTS.

enclosed the native grasses have come back and are flourishing.

This natural recovery of the enclosed range has been demonstrated by the Agricultural Experiment Station of Arizona. A field of 350 acres has been fenced and carefully studied, the conditions of rainfall, moisture distribution, and plant reproduction being observed. It has been shown that the grasses, when protected, not only spread over the ground, but also serve to obstruct the rapid run-off of the water resulting from the sudden and capricious storms of the country. The vegetation causes a greater portion of this water to sink into the soil, where it is stored for future use by the plants.

The Papago Indians of the Southwest, living by crude methods of agriculture, have learned how to make use of the erratic water supply and have demonstrated the practicability of storing flood waters in the soil. Whenever it rains and the water runs down the little gullies near their lands, every man, woman, and child turns out in the storm and builds small dams, or levees, holding the water as far as possible on the series of hastily constructed low terraces. When the water sinks in, they at once plant corn upon the wet surface, and as a result the tribe is fat and happy during the next winter. Observation has shown that even as small an amount of rain as 0.1 inches will cause running water on lands denuded by excessive grazing. If, however, this water can be held back by

the plants, it will soak into the ground and soon increase the supply of forage.

There is a balance which must be preserved between the interests of the cattlemen in keeping the largest possible number of cattle on a range and those of irrigators and the public in general in securing the best ultimate use of the lands. Too many cattle means the destruction of the forage plants, washing of the soil, rapid run-off, and accumulation of silt in the lower rivers. In a larger way it is really to the interest of the cattlemen not to overstock the range, but for immediate individual gain this is always likely to happen unless regulated.

By totally excluding cattle from certain depleted areas it may be possible to restore these after a few years, and the natural growth can be further increased by the construction of inexpensive embankments thrown up by suitable machines or graders, such as to bring out upon the grazing land the waters which from time to time come rushing down the little gullies. It has been shown on a small scale by the experiments at Tucson that these embankments can be made by hand at a cost of less than $1.00 per acre, sufficient to distribute the storm waters and allow these to soak in, resulting in a yield of grass in that dry climate dense enough to be mowed by a machine. Instead of three-quarters of the water rushing off to waste, practically all of it can thus be held on the upper

catchment basins of the rivers and the value of the range land enormously increased.

Under present conditions there is no inducement for any person to guard or protect the open range land, and as a result the valuable forage plants are eaten down so closely as to be destroyed. If, however, one man or an association of men had the exclusive right to the grazing on a certain area for a term of years, it would be to his or their advantage not to overstock the range, but to treat it in such a manner that it would not deteriorate.

Should any law be enacted regulating the temporary use of the public land for grazing, it should be framed in such a way as not to retard the development of irrigation and the settlement of the land by homesteaders. It is probable that the licenses granted for grazing could be made subject to the deduction of relatively small areas for settlement without in any way interfering with the value of these licenses. The great object is to promote the permanent settlement of the country and the making of homes.

In order to provide wise laws, it is necessary to take cognizance of the customs which have resulted from experience. In nearly all counties of the arid states certain practices have arisen in regard to grazing, many of which might be recognized as binding, temporarily at least, until better systems are devised. For example, it has been customary to take sheep from the winter feeding grounds,

where forage raised by irrigation has been provided, and drive them out along certain portions of the cattle range up into the mountain valleys to spend the summer, later bringing them back again by a different route. This right of transit must be recognized in any license given for cattle grazing, and yet must be so guarded as not to be capable of abuse by keeping the sheep too long on the road and allowing them to eat too great a proportion of the vegetation.

Provisions in permits for sheep grazing can be made comparatively simple, since the sheep are always herded and are under complete control. With cattle and horses, however, close herding is impracticable, except in the case of small numbers owned by settlers. It is generally impossible to assign a definite range to a certain owner, as the cattle cannot be kept within bounds without expensive fences, and the fencing of the public domain is and should continue to be illegal. The use of individual cattle ranges is to a large extent impracticable except by owners of great herds. As a rule, it will be necessary to allow the cattle range to be used in common by many owners, the number of head of stock being agreed upon.

This matter of the regulation of grazing has been emphasized in the preceding pages, as it is one of fundamental concern in any new country, and has an intimate relation to the development of irrigation and the complete utilization of the public

domain. The land laws, which, as before noted, have been made with reference to the humid conditions, have not recognized this fact, and thus the rights of the pioneers have been left undefined and to the arbitration of force rather than of law.

CULTIVATED LANDS.

The cultivated lands of the western half of the United States, especially those within the arid region, form but a very small portion of the total land surface, in some states being less than one per cent. Dry farming — that is, the cultivation of the soil without the artificial application of water — has been attempted, but has been only moderately successful west of the 97th meridian, except in the humid regions near the Pacific coast and in a few localities where the conditions of soil and of local rainfall have been favorable. The accompanying map (Fig. 12) has been prepared to illustrate the extent to which dry farming has been attempted. In the extreme western portion of Kansas and eastern Colorado, experiments have been conducted on a large scale, but have rarely been successful; yet at many of the spots shown in the centre of the map, and particularly in Washington, Oregon, and California, wheat and other cereals are successful where the annual rainfall is even less than in eastern Colorado.

One of the notable features on this map is the fact that these dry farming areas are found in

nearly every state and territory of the arid region. Agriculture without irrigation is thus widely prac-

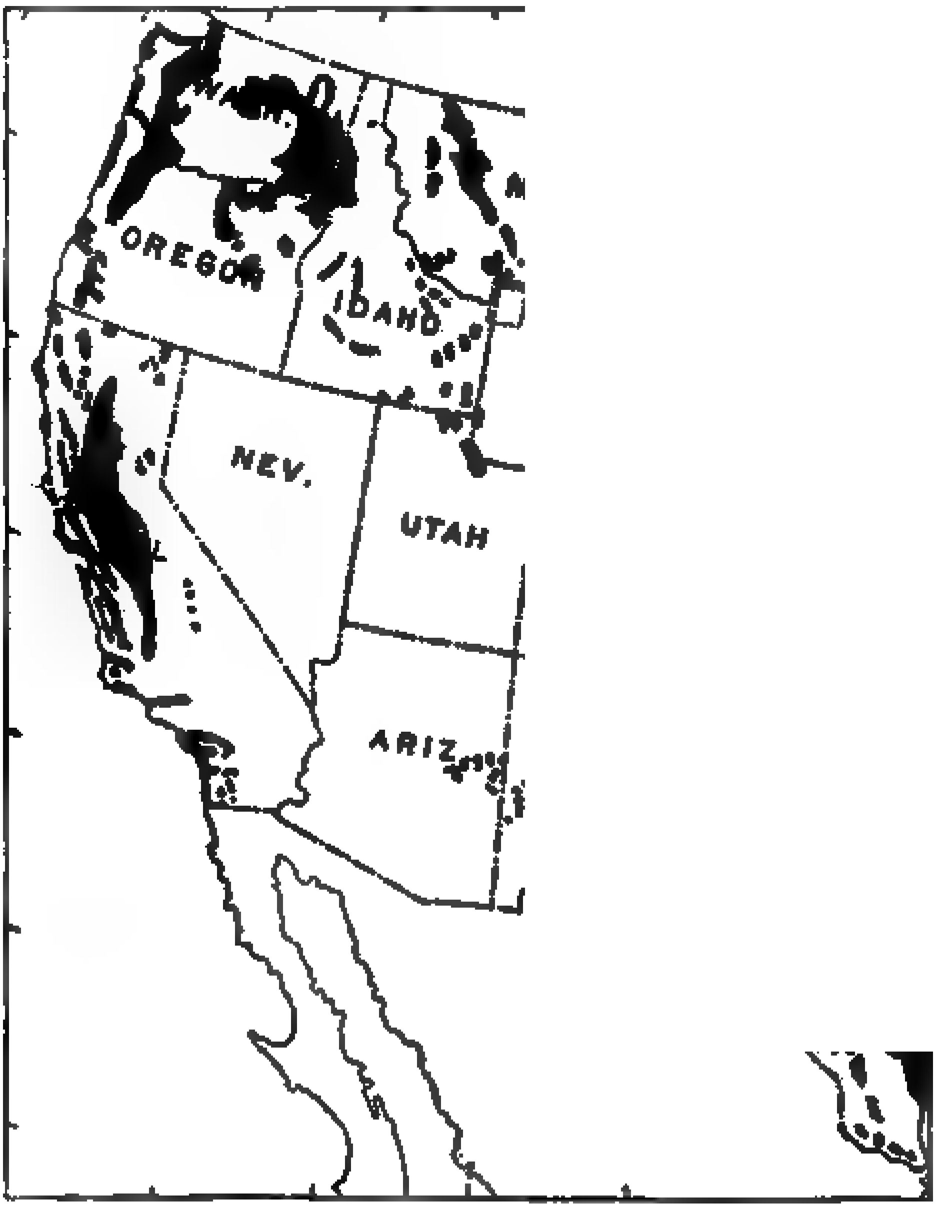


FIG. 12. — Map of dry farming.

tised, although it must be considered as exceptional. The area is gradually being extended as skill is acquired in the cultivation of some of the

more hardy or drought-resisting plants, and as species or varieties suited to the climatic conditions are found. The cereals, such as rye, wheat, and barley, form the greater part of the crops thus raised by dry farming, the growth or development of these being made possible by thorough tilling of the soil and by planting at a season of the year when the largest amount of moisture is available.

As an example of what is being accomplished without irrigation may be given the bench lands around Cache Valley in Utah. These high lands, to which water cannot be brought by ditches, were ten years ago considered as valueless. Experiments were made by the farmers in growing wheat on the lower lands without irrigation, and gradually the cultivated areas were extended up the hill slopes to the higher lands. Various varieties of winter wheat were tried, and it was found that these bench lands, receiving a covering of snow during the winter, were capable of producing good crops of wheat. The yield, although not so large as on irrigated land, is sufficient to afford a fair profit.

There is reason to hope that, with the activity in searching for new and valuable plants, and the numerous experiments being made, the extent of cultivable land can be greatly increased on the areas of good soil for which water cannot be had. It is not reasonable to suppose, however, that dry farming will ever add greatly to the population

and wealth of the arid region; it will rather tend to perpetuate the condition of sparse settlement and careless tilling of large areas. It is only by practising irrigation where water can be had that intensive farming is possible, and with this the best development of the country.

In this connection it is interesting to note the relative proportion of lands cultivated to those which may be considered as cultivable, taking a belt across the United States. The accompanying figure, prepared by Mr. Willard D. Johnson, is in-

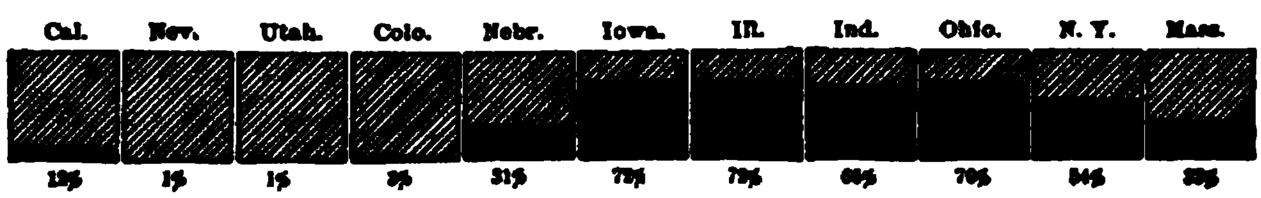


FIG. 13.—Comparison of cultivable and cultivated areas in belt of states across the United States. [The solid black show the cultivated and the cross-lined portions indicate the uncultivated but cultivable land.]

tended to illustrate the great difference which exists. Beginning with Massachusetts, with 33 per cent of the cultivable area in use, the proportion gradually increases westward to Illinois and Iowa, with nearly three-quarters of the land capable of cultivation in crop, and then decreases rapidly, until in Nevada only 1 per cent is utilized. With complete water conservation and systems for its distribution, the cultivated area of Utah, Nevada, and adjacent states might be increased many fold.

The actual amount of land which is irrigable has been variously estimated at from sixty to one hun-

dred millions of acres. There is possibility of wide difference of opinion, since all estimates must be based on certain assumptions as to the completeness with which the floods can be saved and waters beneath the surface brought back to the fields. Noting the wonderful progress in engineering and in various applications of scientific knowledge, there seems to be ground for the most optimistic view. On the other hand, when progress already made is considered, arguments can be advanced against the practicability of utilizing much of the erratically distributed water supply of the arid region. In order to present, however, some general conception of the possibilities of irrigation, the accompanying diagram (Fig. 14) has been prepared, showing by black spots the areas irrigated and by dots the lands irrigable under a better development of the water resources.

The irrigated lands, whose relative position is indicated by the black spots, are of necessity greatly exaggerated; the lands which are actually under ditch are so scattered and relatively small in area that on a map of this scale it is impossible to show them in anything like their true magnitude. The object of the illustration is to bring to the eye the fact that the irrigated lands are scattered throughout the West, forming in aggregate less than 1 per cent of the total land area, and are surrounded by tracts 5 or 10 times as large, which are capable of being irrigated under ideal conditions.

The following table gives in round numbers the relative extent of the grazing, woodland, forest, desert, and improved land in the arid and semiarid

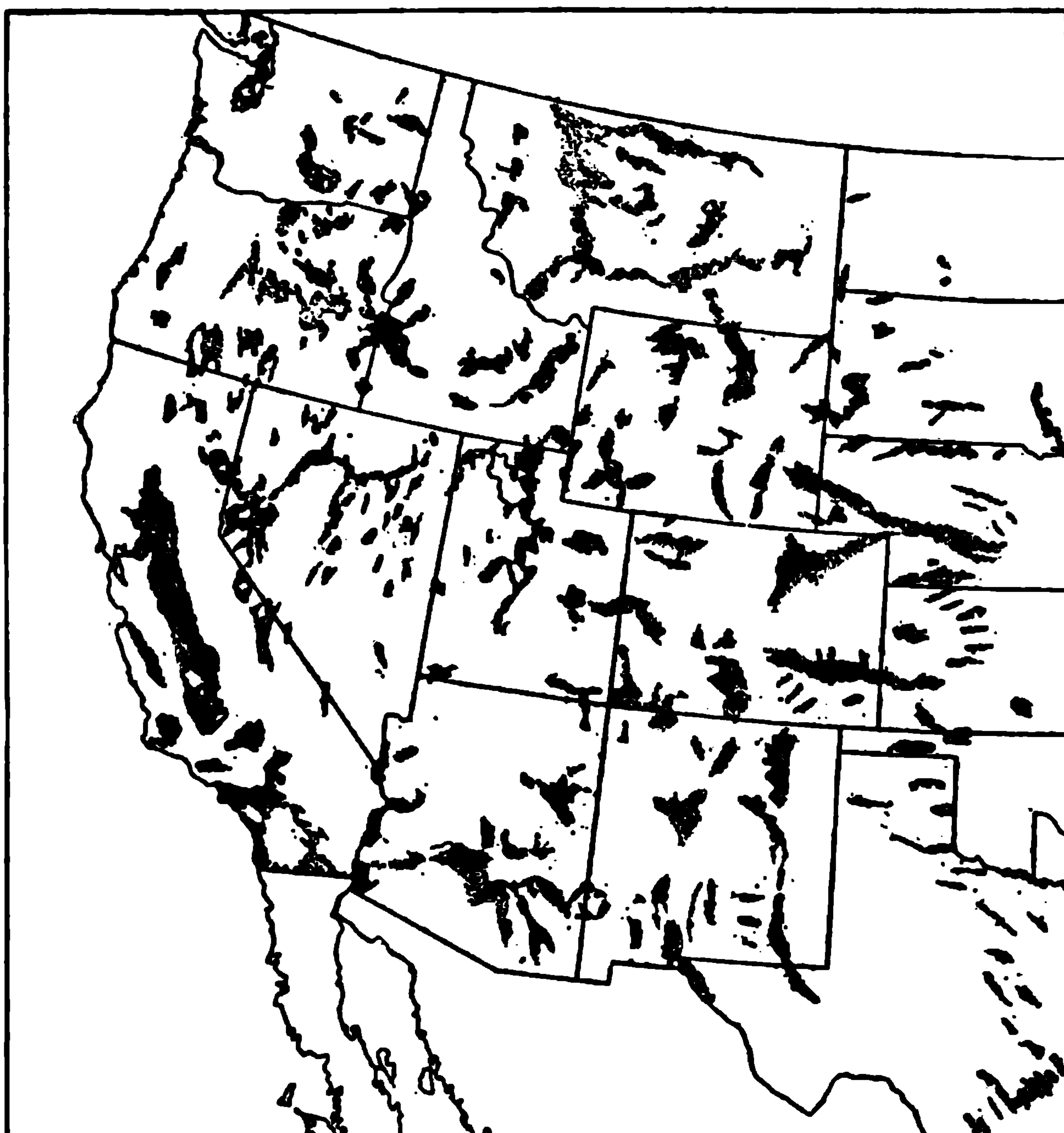


FIG. 14.— Map of irrigated and irrigable lands.

public land states. The totals are given in millions of acres, omitting the figures of less than a million in all cases except where the totals of improved or irrigated land are below one million. There is also

appended a statement of the estimated water supply, in similar terms, assuming a complete development and conservation of the water resources.

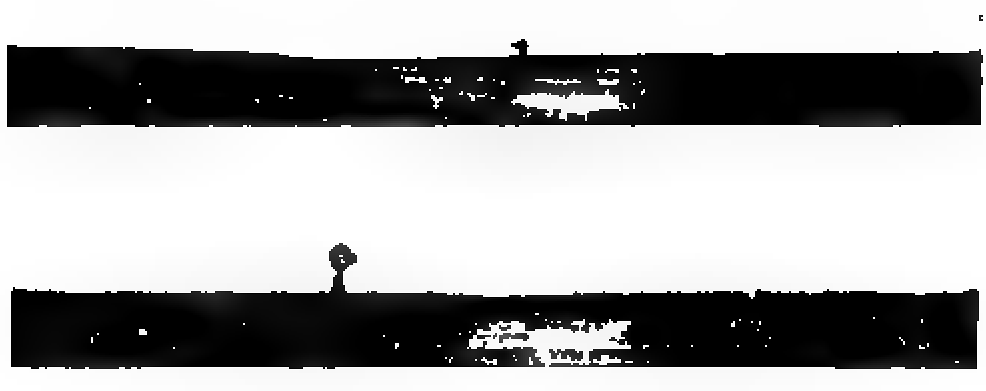
GRAZING, WOODLAND, FOREST, DESERT, AND IRRIGATED LAND, AND EXTENT OF WATER SUPPLY, IN WESTERN PUBLIC LAND STATES, IN MILLIONS OF ACRES.

States and Territories.	Land Surface.	Grazing.	Woodland.	Forest.	Desert.	Improved.	Irrigated.	Water Supply.
Arizona	72	38	9	10	15	0.2	0.2	2
California	99	20	26	18	20	15	1.5	17
Colorado	66	40	14	10		2	1.2	8
Idaho	54	20	19	14		1	0.5	5
Montana	93	56	15	21		1	0.8	11
Nebraska	49	25	2			22		2
Nevada	70	42	6	1	20	1	0.5	2
New Mexico	78	57	16	4		0.5	0.2	4
North Dakota	45	38	1			6		2
Oregon	60	18	17	20		5	0.3	3
South Dakota	49	38	1			10		2
Utah	52	18	14	8	10	2	0.5	4
Washington	43	9	9	23		2	0.1	3
Wyoming	62	39	10	7	5	1	0.5	9

The desert-like lands — those upon which no grazing is possible even in winter or after the rains of early spring — are relatively small; they are found mainly in the states of California, Nevada, Utah, Wyoming, and the territory of Arizona. In all they aggregate about 70,000,000 acres, as noted

on page 28. The surface of these areas is mainly sand and barren rock, the soil often being charged with an excess of soluble earthy salts, so that, even when moistened, plants cannot grow. Such, for example, are the broad flats adjacent to Great Salt Lake, in Utah, and the land around the sinks of the Humboldt, Carson, and Walker in Nevada. Other plains, such as those of south-eastern California adjacent to the Colorado River, have a soil which is fertile and produces large crops whenever water can be had. Portions of these lands are reclaimable by deep or artesian wells, or by storing in reservoirs the intermittent floods of small streams which flow from the bordering mountains.

On Pl. VII are shown views of the broad expanses designated in the geographies of a generation ago as deserts, impassable for lack of water. Beneath the surface of many of these almost boundless wastes water has recently been found, and by means of windmills it is brought to the surface, making oases and rendering possible the use of the land for grazing. The herbage, though scanty, is nutritious; and by placing windmills and tanks at intervals of 10 or 15 miles, cattle can graze over the whole region.



CATTLE ON THE OPEN RANGE.

CHAPTER III.

SURFACE WATERS.

In the practice of irrigation and in the development of the vacant lands of the country the waters of the surface streams play the most important part, supplying fully 90 per cent of the irrigated land. Of less relative importance, but still of great value, are the underground waters obtained by flowing wells or by pumping. The accompanying small map (Fig. 15) shows in a general way the principal river systems of the United States. The most striking feature is the relatively large area drained by the Mississippi and its tributaries. This extends from the Appalachian mountain region on the east to the Rocky Mountains on the west, including a considerable portion of the arid region. To the east of the Mississippi basin are numerous large streams flowing into the Atlantic, and on the north are the Great Lakes draining into the St. Lawrence. All of this part of the United States receives a copious rainfall, usually from 40 to 60 inches per annum, or even more, as shown by Fig. 7 (p. 24).

In the eastern half of the United States the great problem is to take away the excess water

from the lowlands, rather than to bring a needed supply from some river. Drainage ditches are dug, in many respects similar to irrigation canals, but reversed as to slope or grade,—that is, they conduct the water from the land by gradually descending channels into rivers at slightly lower elevation. The methods of building these ditches and the various devices for controlling the water resemble those practised in the arid region.

The three principal tributaries of the main or trunk stream of the Mississippi Valley are the Ohio, the upper Mississippi, and the Missouri. Of these the Ohio is by far the largest in volume, although draining the smallest area of country. Next to this in importance is the upper Mississippi, with smaller volume of flow but larger catchment area; and third, the Missouri, with extremely large drainage basin but relatively small flow. The discharge of these streams illustrates a general law, that, in going from a region of heavy rainfall to one of light precipitation, there is a rapidly diminishing quantity of water flowing in the streams, or "run-off," this decreasing at a more rapid ratio than does the rainfall. There is proportionately less run-off from the land as the annual precipitation diminishes. That is, on the Ohio basin there is not only a larger annual rainfall and snowfall, 40 to 60 inches, but a greater portion of this runs off into the river and flows downward toward the sea; in the Missouri basin the rainfall is

not only less, averaging 10 to 20 inches, but the proportion which finds its way into the stream is diminished, so that while possibly 50 per cent of the rainfall in the Ohio basin appears as water in the stream, probably not more than 20 per cent of that which falls upon the country drained by the Missouri is contributed to the river (see also p. 26).

This law of diminution of the ratio of run-off to rainfall is further illustrated in the still more arid country lying to the southwest of the Missouri. Here is a country where the precipitation is so small, and the proportion of this which appears in the stream so insignificant, that the rivers have not been able to maintain an outlet to the sea, but have shrunk, and, as shown on the small map, have lost their connection with the ocean. They flow from the mountains out into broad valleys, desert-like in character, and here their waters either are lost by evaporation or form in the bottom of the valley a series of shallow lakes, marshes, or sinks. This country is known as the Great Interior Basin, and has within its borders on the east the Great Salt Lake of Utah, the saline remnant of what was formerly a large fresh water lake overflowing into Snake River. West of this, in Nevada, are a number of fresh or slightly brackish lakes, also shrunken remnants of larger bodies of water.

Between the Great Interior Basin and the Mississippi and Gulf of Mexico drainage is the area traversed by the Colorado. This receives its

waters from the Rocky, Wasatch, and Uinta Mountains, and with its large volume has been able to maintain its outlet to the Gulf of California. Its energies have, however, been given principally to downward cutting; and the river, as well as its principal tributaries, flows for the greater part of its course through gigantic narrow can-

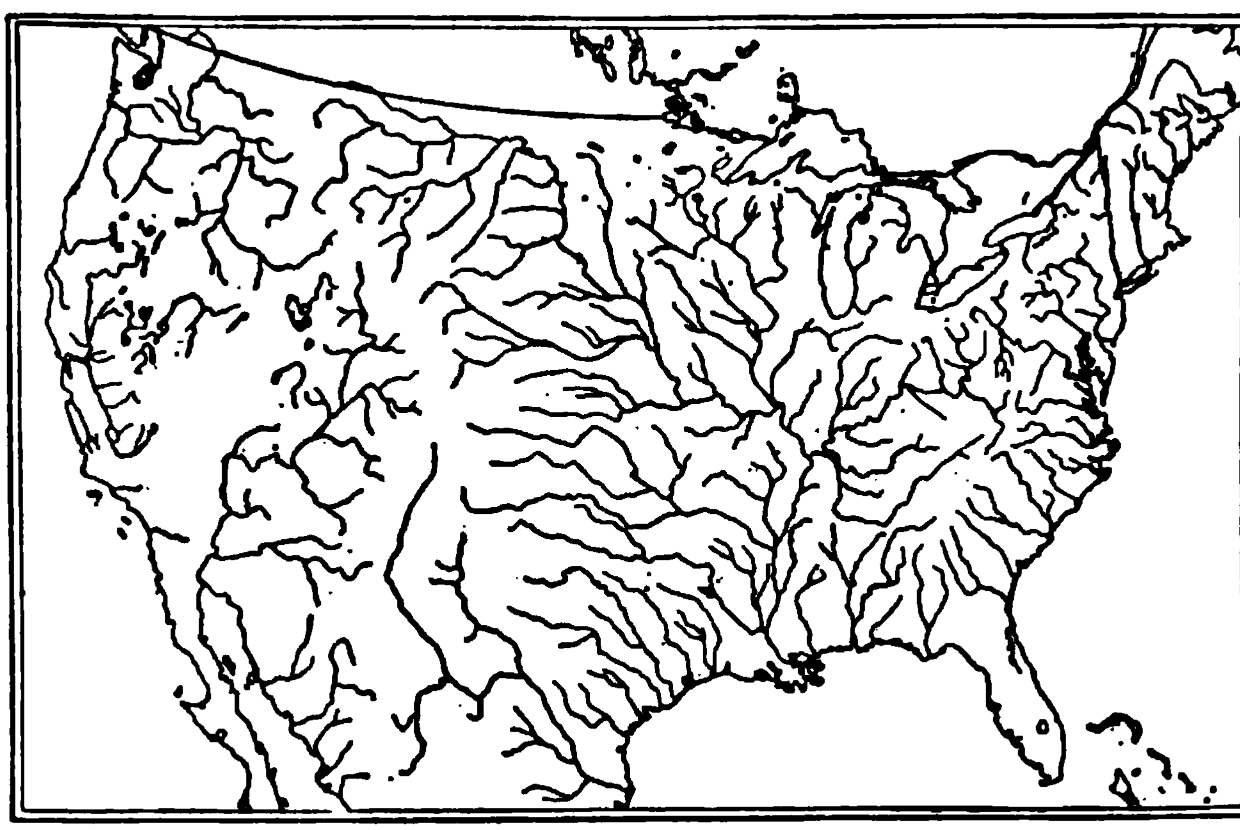


FIG. 15.—Larger river systems of the United States.

yons incised into the hard rocks to a depth of five thousand or even six thousand feet.

North of the Interior Basin is the Columbia River system, receiving the greater part of its waters from regions which are arid or partly subhumid. The principal tributary of importance in irrigation is the Snake River, which rises adjacent to the Yellowstone National Park and flows through

the lava fields of southern Idaho. In these it has cut, for a considerable part of its course, deep, narrow canyons somewhat smaller than, but comparable with, those of the Colorado River.

Below, or south of, the Columbia, are numerous rivers, mostly short, flowing from the Cascade and Coast ranges into the Pacific Ocean. The principal river system of this group is the Sacramento, which, with its equally important tributary, the San Joaquin, drains the great valley of California, discharging into the Bay of San Francisco and connecting with the Pacific Ocean through the Golden Gate.

It is not the main or trunk streams above enumerated which are of chief importance in the development of the arid country, but rather the smaller tributaries, most of which cannot be exhibited on the map of the United States unless it is made of almost unwieldy size. The main streams are too large to be controlled by ordinary hydraulic works for irrigation or power, and in their lower courses they have, as a rule, attained such gentle grade or slope that they have little industrial value except for navigation.

In the upper course, where the streams are small and descend rapidly with falls and cascades, or lower, where the swiftly flowing waters rush along over beds which slope at the rate of ten to twenty feet per mile of length, it is possible to erect structures by which power can be developed or the

waters taken by gravity to the lower lying fertile lands. Head works can be placed on the banks of these streams, or dams built across their beds, raising and controlling the waters.

PERIODIC FLUCTUATIONS.

If the rivers coming from the mountains flowed at a uniform rate month by month and year after year, it would be a comparatively simple matter to construct hydraulic works; but this is not the case. There are very few streams which do not fluctuate widely in their flow, delivering during certain days or weeks volumes of water many times the average flow, or falling in late autumn to a discharge so small that the stream becomes almost worthless for industrial purposes. Not only do the rivers change from season to season, but in successive years there may be a wide variation. Sometimes for several years there may be apparently an increasing volume of water and then a long period of drought with diminished flow for nearly a decade. It is this erratic character which makes difficult, expensive, and sometimes profitless, the works for utilizing the water resources.

In the humid East the variations in river flow, while great, are not usually so extreme as those of the arid region. The typical river in spring flood increases to a volume several times that of the ordinary flow, then gradually diminishes in discharge, toward the time of summer drought, drop-

A FLOOD IN SALT RIVER, ARIZONA.

ping to a third or a quarter or even less of the average, to rise again as cold weather comes on. In contrast to this may be taken, for example, the Gila River of southern Arizona, — a stream of great importance in the development of the rich land of that territory, but one offering many difficulties owing to its erratic character. Frequently its flow for months at a time will practically cease, and the water stand in pools along its channel. Suddenly a violent flood occurs, rising to a discharge of ten thousand or more cubic feet per second, but, in a day or two, the river drops to a small stream, gradually diminishing until nearly dry. Sometimes these floods follow one after another, in rapid succession, washing down immense quantities of gravel, sand, and clay, and piling these up along the channel or overwhelming and washing out the dams and head gates built for irrigating purposes and the bridges, as shown on Pl. VIII.

In sharp contrast to the Gila River of Arizona may be cited the Deschutes River of central Oregon. This, although within the borders of the arid region, has a wonderfully uniform flow, not varying in height more than a foot or two throughout the year and from one year to another. The cause of this evenness is due mainly to the fact that the catchment area of the river is for the most part covered with lava, the pervious rock serving as a reservoir or series of regulating chambers for the stream at the time of melting snow

or after a storm. The excess water doubtless percolates into the lava, to be delivered through many tortuous channels into the stream at various points along its course.

In order to illustrate the ordinary fluctuations of a river of the arid regions there is given herewith a diagram (Fig. 16) showing variations in quantity of flow of the Rio Grande at Embudo, New Mexico, for the years 1896, 1897, and 1898. This exhibits a great difference in volume of floods during the three successive years. Beginning in January, 1896, the flow was approximately 500 cubic feet per second, this continuing with slight rise during February, and on the last of March reaching 2000 cubic feet per second. In April there were fluctuations, and about the 7th of May the flood culminated at 3000 feet, the discharge dropping off during May and June to the ordinary summer flow of about 200 second-feet, interrupted occasionally, as shown by the diagram, by small floods of short duration.

In 1897 the discharge in January and February was less than in the preceding year, and the amount gradually increased, culminating during the latter part of May in a volume of 8745 second-feet, nearly three times the size of the greatest flood of the preceding years. During June the river continued high, with large flow, not reaching low water until August. There was a second flood reaching 2000 second-feet in the middle of October, this

FIG. 16. — Diagram of daily discharge of Rio Grande at Embudo, New Mexico, for 1896, 1897, and 1898.

FIG. 16. — Diagram of daily discharge of Rio Grande at Embudo, New Mexico, for 1896, 1897, and 1898.

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gradually decreasing toward winter. In 1898 there were three well-marked floods. The first occurred in the latter part of April, the water dropping during May at a time when usually there is the greatest discharge. In June there was another flood, interrupted by a short decline, and in July occurred the greatest flood of the year, this reaching about 4500 second-feet. The amount rapidly declined to the summer flow, and there were no floods during the remainder of the year.

The average flow for the year 1896 was 645 second-feet; for 1897, 1497 second-feet; and for 1898, 1157 second-feet. In other words, during 1897 the river discharged more than twice as much as in 1896. It is not unusual for a stream to deliver two, three, or even four times as much in one year as in the preceding or succeeding year. These facts as to the quantity of water and the range of fluctuations are essential in any discussion of irrigation, and particularly of the extent to which the arid lands can be reclaimed.

This diagram of the Rio Grande is typical of drawings which could be made for most of the rivers of the arid region. In nearly all cases they have a well-marked period of flood from April to June, during which time the greater part of the water for the year flows away. This is the time of planting and germinating seeds, and there is usually water in abundance for thoroughly wetting the ground. Later in the year, however, when the

crops are beginning to mature, the available supply for irrigation is greatly reduced, and it is no longer possible to supply the large areas planted in the spring.

In looking at this diagram the idea at once occurs that it should be a simple matter to hold over some of the excess water of the spring, diminishing the height of the floods, and to turn this back into the streams to replenish, or fill up, the depressions shown in the diagram; in other words, to regulate the discharge to a more uniform condition, changing the diagram from one of erratic points to a uniform curve.

For comparison with other rivers, and especially with eastern conditions, a diagram (Fig. 17) of the flow of Susquehanna River at Harrisburg, Pennsylvania, for the same years is given. This carries a far greater volume of water, as indicated by the figures on the side of the diagram. The most striking feature is the large number of the floods, the short period of duration of each of these, and their irregularity as regards time of year. Most of them occur in the early spring or late fall, June, July, August, and September being times of low water.

Measurements of many important streams of the United States have been made, and diagrams similar to the above constructed, illustrating this variation in river flow. They are, for the most part, similar to the figures given, but careful comparison

FIG. 17. — Diagram of daily discharge of Susquehanna River at Harrisburg, Pennsylvania, for 1896, 1897, and 1898.

brings out individual peculiarities of each river, dependent upon topographic and climatic conditions. The study of a series of such diagrams brings out clearly the fact that in the flow of streams, as in the quantity of rainfall, there are often cycles of irregular periods during which the quantity increases with more or less persistency, and then decreases for a number of years in succession. The attempt has been made to ascertain whether there is any definite periodicity for these cycles, and some investigators have occasionally succeeded in demonstrating, to their own satisfaction at least, that there is a regularity, but unfortunately no two students are as yet agreed upon the length of time of these. The cycles, if they may be so termed, are probably not coincident in different parts of the United States. The rivers of California may be very low for a series of years, while during the same period those of Texas or the Atlantic coast may have more than a normal discharge.

In what has been above stated, the assumption has been made that there are no large lakes along the course of the rivers under discussion. In various parts of the United States, however, particularly in glaciated portions embracing New England and states adjacent, the courses of the streams have been disturbed by the incursion of the ice sheet and by the material dropped in its retreat. The boulders, gravels, and clays, irregularly de-

posited, have produced numerous lakes which serve to retain, for a time at least, the precipitation upon the surface, holding back the floods and allowing the water to escape with comparative uniformity, thus giving rise to rivers of steady flow. This condition is limited to a relatively small part of the country, but the great development of water resources which must take place within the arid region will first be patterned largely after the results attained by nature. The upper courses of the streams must be blocked by suitably constructed dams, forming lakes to hold the floods and to regulate the flow throughout the season when water is needed.

The fluctuations which have taken place in the volume of different rivers from season to season and from year to year are believed to have a certain range, which can be ascertained by measurements carried on through a number of years in succession. The results at present obtained often appear to indicate that the rivers are steadily diminishing in volume, and the question is frequently asked whether the rivers are not drying up. It has been argued that, in the western part of the country at least, there is a progressive desiccation, and that, as time goes on, less and less water will be available. From geological evidence it is certain that in comparatively recent times, as measured by the age of the rocks, the climate of the West was far more humid. On the

other hand, records of weather conditions obtained for various parts of the United States and for European countries, some of these extending over a period of one hundred years or more, lead us to believe that the present climate is permanent as regards historical periods. In other words, for the few hundred or thousand years that men have made observations or records, there has been no decided and permanent change in climate; although for the millions of years for which geological data are available, there are found to be decided differences.

From these and other considerations it is safe to assume, as in the case of the rainfall, that the quantity of water in the rivers of the country is not permanently increasing or diminishing. It is evident, however, that modifications are taking place in their behavior, especially as regards the amount and duration of floods and of low water. The changes introduced incident to civilization, — the making of roads and trails, which act as conduits or ditches, the draining of swampy places, the cutting of the trees, the burning of forests and underbrush, — all exert a more or less direct influence upon the rapidity with which water runs off the ground after a rain and finds its way into the streams. Thus there can be no doubt that springs and smaller creeks at least have been destroyed, or their flow greatly modified.

SEEPAGE.

The streams within the arid regions of the United States, having their sources amid the high, rocky, or forest-clad slopes of the mountains, descend rapidly toward the fertile plains, which often stretch far out to the horizon. Their downward course is seldom an uninterrupted one. Usually at one point or another they meander for a time through upper valleys or parks, whose summer verdure is in striking contrast to the sunburned plains beneath. Leaving these, the streams enter rocky defiles or narrow canyons, to again emerge upon a narrow lower valley; and, receiving tributaries on the way, they finally pass through the foothill regions and out upon the vast fertile plains. At about this point a gradual transition takes place in the character of the channel, which, from a rocky, torrential, or gravelly stream-bed with rapid fall, broadens into a shallow, shifting, sandy channel, in which the stream, dividing and subdividing in times of low water, finally, by imperceptible degrees, loses itself. In times of flood the water may fill the broad sandy waste, and after a few days force its way far out to join some lake, or finally reach some perennial stream making its way to the ocean.

In its course the water of the stream may be diverted at any point. It may be taken out in the upper parks or valleys high among the mountain

peaks, and used during the spring or summer to increase the growth of the forage plants; or it may be utilized in the lower valleys among the foothills, or out upon the margin of the plain, or upon the lower plain itself. If the stream channel were like an iron pipe or conduit, in which the water, once received, must pass along until discharged into some branch or at the lower end, the estimation of water supply would be comparatively simple. It would be assumed that whatever water came into the pipe at any point must come out at some other; or, in other words, that the quantity to be dealt with would be constant; and our account books would balance. This, however, is not the case in nature.

If among the mountains we measure all the visible affluents of a stream, add these together, and then measure the volume of the main stream a little distance below, we shall generally find that the aggregate volume is greater than the sum of the visible tributaries. Water has come in imperceptibly, this action continuing through a great part of the year, — after the frost has left the ground and until late summer. Going down-stream to the edge of the plain, there will be found, however, a different condition of affairs. If at the edge of the foothills we measure all of the creeks, add the results together, and then measure the main stream a few miles below, it will usually be found that this latter volume is less than the sum

of the various tributaries. This decrease will be found to continue at a greater or less rate, with perhaps an occasional increase.

This irregularity in the behavior of a stream, increasing and decreasing without visible cause, is explained by what is commonly known as seepage or percolation. In the more elevated portions of the basin, with cooler climates and larger water supply, the rocks, more or less saturated by the rains and melting snows, yield their waters to the streams; but in the lower and dryer part of the basin, where the rocks or soils are loose or unconsolidated, they receive and conduct away some of the river water, until all may be taken, transmitted laterally, and given out imperceptibly to the dry air. Direct evaporation from the surface of the flowing stream also aids seepage in robbing the rivers in their lower courses.

Under natural conditions a river gradually increases in volume, both by tributary surface streams and by percolation, to a certain point, and then gradually loses some of its volume by imperceptible degrees. This point is usually at or near the lower foothill region, and in a general way corresponds with the place where, from slope of channel and other features, canals and ditches can be most economically constructed to carry water out to the edge of the lower plain.

This point of maximum available flow is often coincident with other favorable features, as regards

both climate and soil. Being protected by the foothills, winds are not so severe, and frosts do not come so early in the fall nor linger so late in the spring. This part of the river basin is thus peculiarly favored for successful agriculture by irrigation, and if physical conditions alone had been considered, a concentration of efforts at such places would have resulted in the largest and best utilization of the public lands. The progress of settlement has, however, not followed any systematic course tending to make the largest amount of land available for settlement; and we now find that on each stream the best lands and the best opportunities for completely utilizing the water have sometimes been neglected through lack of knowledge or experience on the part of pioneers.

A prospector, weary with the search for precious minerals; a cattleman, choosing a home ranch; or a pioneer farmer, seeking a location with ample space for his growing family, has picked out what seemed to him at the time the most desirable spot, and, by his own efforts, or aided perhaps by neighbors, has dug a small ditch where the ground was most easily worked by simple farm tools. Above or below, another ditch has been taken out by later comers, attracted by the success of the first man, and year by year, as more people settled along the stream, new ditches have been dug and old ones have been enlarged.

The older ditches have usually had an abundant

supply, and their owners have become accustomed to use water freely, saturating the ground and filling the subsoil. The excess water, slowly percolating downward and outward, progresses toward the lowest point, and finally reaches daylight on the lowlands (Pl. IX). The rate of movement is extremely slow, being usually only a few inches a day. Weeks, months, or even years may be required for the passage of any particular drop of water from the irrigated field through the ground and out into the river bed, so that the increase of stream flow may not be recognized for several years after irrigation has been introduced. When once an extensive area has been thoroughly saturated, the seepage may continue for a considerable period. This effect of irrigation in increasing the natural seepage is now well recognized, and it is often esteemed a benefit to lower portions of a valley to have water applied to lands higher up, since by so doing the amount available in the latter part of the crop season for the lower land is increased. On the other hand, as discussed on page 226, the seepage may grow to such an extent as to become a source of annoyance and even of injury.

To illustrate the effect of seepage, an example may be taken of a typical catchment basin, in which there is an upper valley, a long middle or lower valley, and beyond this the broad expanse of margin of the plain. The inhabitants of the highest valley, by diverting the spring floods to the fields, and

A. SEEPAGE WATER APPEARING ON LAND FORMERLY DRY, NEAR RINCON, CALIFORNIA.

B. DREDGE CUTTING CANAL TO RECEIVE SEEPAGE WATER.

distributing these over pasture or hay lands, put to beneficial use waters which otherwise would be wasted, since at that season there is an excess all along the stream. A part of the water thus used percolates back to the stream in the lower end of this valley, and adds to the volume available for the irrigators in the next or middle valley. If, however, this utilization in the highest valley continues throughout the summer, when the heat and consequent evaporation are greater, it may be possible to divert all of the flowing water from the stream, by spreading it upon the fields, and leave the channel completely dry save for the seepage, which continues to flow. Under this condition the inhabitants of the middle valley are deprived of the natural flow of the stream, and have only the seepage water, instead of the ordinary discharge increased by seepage.

There is thus a time of year, shortly after the occurrence of the spring floods, when continued utilization of the waters in the highest valley becomes, not a benefit, but an injury, to the people below. The same thing is true of the utilization of the water in the middle valley. The extravagant use of the water early in the year in the middle valley may be of advantage to those below, in adding to the summer flow through seepage; but further utilization, in taking all of the water out of the stream, interferes greatly with the supply at points farther down-stream.

There is for every point along a river of any considerable length a time when the diversion of the water at points far above becomes, not a blessing, but a curse. This time varies, not only with the amount of water in the stream and the amount taken out, but also with the weather conditions, a dry year resulting in diminished seepage and earlier passing of the critical point, and a cool year in retardation of the time when diversions above become an injury. This date, as a rule, gradually grows earlier and earlier as years go by, for with the usual extension of irrigating systems comes greater economy in the use of water, and with greater economy must be less seepage. With increased irrigated area a smaller amount of water is put upon each acre of the fields, and finally only enough to supply the needs of the plants. When this point is reached, there should be theoretically no artificial seepage, and then no benefit to points below. This, however, is an extreme condition rarely realized.

The necessity of ascertaining, not only the water supply, but also the modifications due to artificial diversion of the water, is emphasized by consideration of the prevalent customs and usual legislation regarding water rights. As a rule, throughout the arid region, priority of utilization carries with it the first right to continued employment. The man who along the course of the stream first took out water and cultivated a given piece of land, is, by

custom and law (see p. 291), entitled to take out the same quantity of water to this land, regardless of his neighbors. The man who came second, whether by a day or by a generation, has a secondary right, and can use forever the amount of water originally diverted and put upon the cultivated soil, provided there is sufficient to supply the first comer. The man who is third in point of time can utilize his share only after the first and second men have had their prior claims satisfied; and so on down the list, the last comer being compelled, if necessary, to leave the water untouched until all have had the exact quantity legally claimed. By increasing or diminishing the flow of a stream at any point through seepage the values of farm lands may be greatly affected.

IMPORTANCE OF STREAM MEASUREMENT.

The above discussion of one of the problems of water distribution illustrates the difficulties in the way of the best development of the arid lands, and shows the necessity of thorough and accurate knowledge of all of the conditions. The matter is further complicated by the manner in which political divisions have been drawn, regardless of natural boundaries. In nearly all cases the more important streams flow through several counties, each of which has its own peculiar custom in regard to the distribution of water, and in which the inhabitants and officials are somewhat jealous of

other counties, or at least are not inclined to work in harmony with them. The most difficult case, however, is where state lines intersect drainage basins, as it is then almost impossible to secure any consideration by one state of the rights of people lower down the stream in another state. Each year these interstate questions are becoming more and more complicated, and the demand for laws or regulations which shall impartially settle disputes is more urgent.

There are also important streams, such as the Rio Grande, which flow along or across the borders of the republic and give rise to international complications similar in many respects to the interstate questions. While in each case there is necessity for accurate and detailed information regarding local conditions, yet it should be possible to determine some broad principles applicable to all. A thorough knowledge of the water supply, its fluctuations and limitations, is therefore essential, in whatever aspect the future of the public lands may be considered; but the difficulty of obtaining systematic knowledge can best be appreciated when the vast extent and wide distribution of the national domain are considered.

The principal streams of the arid region have been measured by the Division of Hydrography of the United States Geological Survey as part of its investigation of the extent to which the arid lands can be reclaimed by irrigation. This forms

a portion of the general study of the water resources of the United States, and the opportunities for utilizing these in power and other industrial purposes, as well as in agriculture. The flow of rivers has been systematically observed in various sections of the United States, to obtain facts for use in considerations of problems relating in the East mainly to power development, and in the West to irrigation.

By far the greater portion of the vacant public lands — over 95 per cent — is classed as arid or semiarid in character and, as shown in earlier pages, depends for its future value not so much upon altitude, mineral contents, or geological structure as upon the presence or absence of water. Thus it is that the question of water supply, its quantity, quality, and availability, is one upon which turns the future of the national domain. When the essential facts concerning the water are clearly known, it will be possible to determine upon the best legislation for the reclamation of portions of this vast area, and the dedication of other portions to various purposes, such as grazing and woodland.

It is a fact now generally recognized that, owing to the scarcity of water, only a small portion of the public domain can be reclaimed for agriculture; but this amount, though small when compared with the whole area, is in the aggregate larger than the territorial extent of some of the states, and will sustain a population of millions. After all of the

land that the water will cover has been utilized for agriculture by means of irrigation, there will still remain hundreds of millions of acres of rich land suitable for grazing and for the growth of forest products.

METHODS OF STREAM MEASUREMENT.

The operations of measuring the volume of a flowing stream, although not complicated, possess an element of mystery to the average citizen, largely because he has not been accustomed to consider fluctuating quantities. It is possible to form a very definite conception of the amount of water standing in a pond or reservoir, but in the case of a stream the quantities considered are of water in motion, and therefore another and somewhat novel element enters, that of time. The statement of the quantity of water in a stream is dependent upon the time considered, and therefore it is necessary as a first step to take some unit. This is usually the second, although the minute is occasionally used.

In the United States the unit of quantity in water measurement is the cubic foot, although the gallon is largely employed by engineers and others having to do with city waterworks. The objections to the gallon are that there are several gallons of different size, and that the quantity is so small that figures of stream flow run up into inconveniently large numbers. The gallon in customary use is

equivalent to 231 cubic inches, or 7.48 gallons make 1 cubic foot.

There are other units frequently employed in statements of the amount of water, the most important being the acre-foot. This is used particularly with reference to waters stored in reservoirs. An acre-foot of water is the amount which would cover one acre, or 43,560 square feet, to a depth of one foot; or, in short, 43,560 cubic feet, or 325,851 gallons. One cubic foot per second flowing for twenty-four hours will cover an acre to a depth of 1.98 feet. It is customary in round numbers to state that a cubic foot per second for a day is equivalent to 2 acre-feet. The contents of reservoirs built for city water supply are usually stated in millions of gallons, while those for irrigation are almost always given in acre-feet. It is convenient to remember that 1,000,000 gallons equal a trifle more than 3 acre-feet (3.069).

If we imagine a small stream filling a rectangular conduit 1 foot wide and 1 foot deep, we have a stream whose sectional area is 1 square foot. The volume of this stream will vary in proportion to the speed with which the water flows through the conduit. This speed is most conveniently expressed, as above noted, in the rate per second, the foot being used as the unit of distance. If, for example, the water is moving at the speed of 1 foot per second, it follows that there is a flow of a volume of 1 cubic foot per second. If the water is

moving at a higher speed, as for example 5 linear feet per second, the volume will be 5 cubic feet per second. In the same way, if the conduit is 5 feet wide and 20 feet deep, the areal section is 100 square feet, and if the average flow is 2 feet per second, the total discharge will be 200 cubic feet per second. This expression, "cubic feet per second," is frequently abbreviated to "second-feet."

From what has been above stated, it is apparent that the measurement of the flow of a stream consists in obtaining the width, depth, and velocity. If these were perfectly definite or fixed quantities, the operation would be extremely simple; but as streams occur in nature, these quantities are not always precisely bounded, and considerable judgment is required in assuming the limiting points. For example, the measurement of the width of a stream necessitates an assumption as to the actual point or line where the moving water ends and the bank begins. As the natural banks are always irregular, the width of a stream may vary considerably in going short distances. The shores are usually shallow, and there are often little areas of stagnant water, or even returning currents creeping along the shore, so that it becomes necessary to decide from inspection where the shores may be said to begin and end at the particular locality where the measurements are made.

The depth of a stream is also a variable quantity. Outward from the shore the depth gradually

increases toward the centre, and then shallows toward the farther bank. Often there are bars or deposits of sand, gravel, and boulders, making the bottom irregular, so that a sounding pole or line may find a place on top of a stone or by its side, making considerable difference in the reading of the depth. It is thus necessary to make a number of measurements of depth by soundings across the stream, taking these at intervals of 1 foot, 5 feet, 10 feet, or more, according to the width of the stream and the irregularity of the bottom.

If the water were perfectly still it would be an easy matter to read the distance from the bottom to the top, but with most streams there are small ripples or waves produced by the wind and by the flowing water, so that in ascertaining the depth allowance must be made for the wave motion as the water rises and falls on the measuring pole. In very careful determinations there are also found to be fluctuations of the height of the water due to the rhythmic flow, the surface slowly rising and falling through periods of from one to two minutes or more. This slow oscillation can be noted by any simple device which stills the waves; for example, by observing the water in a pipe whose lower part beneath the water is perforated.

These measurements of the width and of the depth of a stream can be readily made by measuring lines or sticks; but the third factor — that of speed — requires additional apparatus, as the ele-

ment of time must be noted. The stream does not move like a train of cars or a rigid bar, all portions travelling at the same rate. On the contrary, each particle moves along a path of its own, not necessarily parallel with the banks, but usually with more or less circular or gyratory motion. In the centre of the stream, or where the water is deepest, it can be readily seen by the eye that the water is moving faster than near the shore. The place of greatest motion is about one-third of the distance beneath the surface, this being the locality where the water is least impeded by friction. Toward the sides and bottom the rate of flow gradually diminishes, the velocity being governed by the roughness of the surface, boulders or projections causing eddies and setting up disturbances which retard the forward motion.

Floats.

The simplest way of obtaining the rate of flow is by means of small objects floating upon the surface. For example, a path 100 feet in length can be laid off along the side of a stream, each end of the path or course being marked by a stake. A chip can be thrown into the stream above the upper stake and the exact second noted when it passes this point, and also when it passes the lower point 100 feet below. If 20 seconds were required, the velocity of the chip was 5 feet per second. If the first chip or float followed near the centre

of the stream, other floats can be tossed in so that they will travel in lines intermediate between the centre and the banks. These will move at the rate of 4 feet a second, 3 feet a second, and so on. If they are well distributed across the stream, the average will be approximately the surface flow, which for convenience may be taken as 3 feet per second.

The entire stream is not flowing as rapidly as the surface, and it is usually assumed that the water as a whole moves at about 0.9 the average surface velocity. It is necessary therefore to multiply the 3 feet per second surface flow by 0.9, giving an average rate of flow for the whole stream of 2.7 feet per second. If we have found that the width is 20 feet, the average depth 4 feet, the area of cross-section is 80 square feet, and the rate of flow, 2.7 feet per second, gives a volume of 216 second-feet.

In making this simple computation it is usually desirable to take the precaution of dividing the stream, if of considerable width, into several sections lying side by side, and considering each of these as independent, for the reason that the sides of the stream, where the depth is less, have the least velocity, and the centre of the stream usually has the greatest velocity. For accuracy in computation the shallowest cross-section, say 10 feet in width, should be multiplied by its velocity, and the deepest cross-section, also of a uniform width of

10 feet, multiplied by its velocity; and so on with each portion of the stream. This is because of the fact that the total area multiplied by the

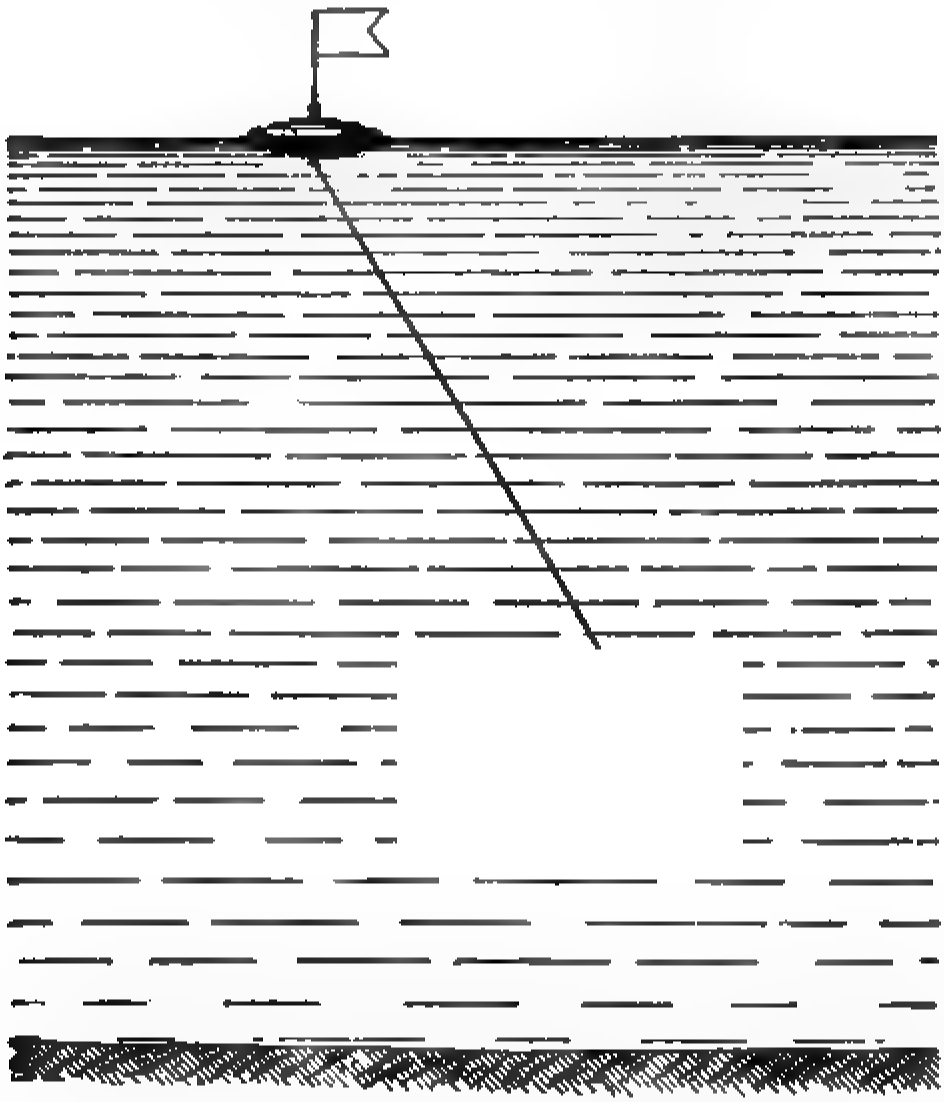


FIG. 18. — Double or submerged float.

average velocity does not give the same result as obtained by the method just described.

This method of obtaining the discharge of a stream by means of floats can be employed by any

person of fair skill and judgment, and will yield results suitable for most practical purposes. It is susceptible of refinement in many ways. For example, if the stream is wide, stakes can be set on opposite sides of the bank in order to locate accurately the course of 100 or 200 feet. The surface floats can be replaced by rods or submerged floats; that is, poles or tubes of tin or other metal can be prepared and weighted at the bottom in such a way as to stand vertical in the water, just clearing the bed of the stream and with the top appearing above the surface. Such floats give very nearly the average velocity of the water of that particular section. Submerged floats can also be used, these being small closed vessels, usually short cylinders so loaded as to float at a given depth, and connected by means of a small cord or wire to a marker floating on the surface, as shown in Fig. 18. It is difficult to determine the exact position of submerged floats above the bottom and to make allowance for the influence of the wire and the marker.

Current Meters.

The difficulty and even impossibility at times of using floats, and the various uncertainties connected with them, have led to the adoption of other devices for obtaining the velocity by less direct methods. The most common of these is the current meter, an instrument which consists essentially of a small mill or wheel held at a given point in the water

and caused to revolve by the stream, the speed of revolution being dependent upon the speed of the water. This rate of revolution may be noted in a number of ways, either by means of small wheels connected with a dial, or by a device making a rap or click, or by some form of electric "make and break." The latter is the preferred form, since the meter can then be used in a great variety of ways and at a considerable distance from the operator.

The accompanying view (Pl. X, *A*) is of an electric current meter, one which may be considered as illustrative of many different forms. On the extreme right is shown a series of conical cups arranged on the periphery of a wheel in such a way that the water striking the open face of the cups causes them to revolve. Each revolution "makes and breaks" the electric current passing through the spindle or bearing of the wheel. This electric impulse is transmitted through a double insulated conducting cord, the battery supplying the impulse being connected at the far end of this cord. In the view the battery box is open, and the small bisulphate of mercury cell is shown taken out of the box and with the zinc pole removed.

Behind or at the left of the revolving wheel or head of the meter is seen the device for supporting it with a lead weight below, and beyond this the tail of the meter, consisting of two sheets of metal at right angles to each other, intended to hold the

A. ELECTRIC CURRENT METER, CONDUCTING CORD, AND BATTERY

B. METHOD OF USING ELECTRIC CURRENT METER FROM SUSPENDED CAR

head of the meter horizontally in the flowing water. When the meter is lowered into the stream by means of the conducting cord, the head begins to revolve, and each revolution opens and closes the electric circuit, this fact being made known by a little buzzer or sounder about the size of a watch attached to the back of the battery box. The engineer or hydrographer using the instrument can put this battery box, with sounder attached, in his pocket, and can hear the click, click, click, as the meter wheel revolves under the water. By holding his watch in his hand and noting the number of clicks during, say, 50 seconds, he can readily obtain the number of revolutions per second. For example, if he counts 100 clicks in 50 seconds, the meter head is obviously revolving at the rate of two per second. Referring to the table constructed for the purpose, he notes that two revolutions per second are equivalent to a speed of 5 feet per second, and thus he obtains at once the speed of the water at the particular point where the meter is placed.

In using a current meter the chief operation consists of placing the meter at a sufficient number of points across the stream, and from the surface to the bottom, so as to obtain a full knowledge of the rate of flow of each portion of the current. In rivers and creeks of ordinary size it is usually sufficient to make observations at intervals of, say, 10 or 20 feet horizontally, so that there will be from

eight to sixteen localities of measurement across the stream. The velocity is usually found to vary but little from one of these localities to another, unless there are obstructions, such as large rocks or snags. In deep streams it is necessary at each of these localities across the section to observe the velocity just below the surface and at intervals of from 2 to 5 feet to the bottom. In very shallow streams usually only a single measurement at each point across the stream can be made, as the meter requires some space in order to be submerged and not strike the stones on the bottom.

When these observations have been made at evenly distributed points in the vertical, the average of them may be taken as the velocity at this locality, or the figures can be plotted graphically and the average velocity obtained by measurement of the drawings. If the localities of measurement of speed are taken at intervals of, say, 10 or 20 feet across the river, the average depth of each of these portions of the stream should be multiplied into the width and into the average velocity; the flow of each portion of the stream being thus separately ascertained, the total will give the complete discharge.

In order to use the current meter successfully, it is necessary to be able to reach all parts of the cross-section. This can be done by a plank laid across a narrow brook, or by a bridge, if favorably located, across the larger stream. Where there are

no bridges, boats are occasionally used, although in flood times these are often dangerous. A device which is largely used consists of a stout iron or steel cable stretched across the stream at a convenient place and suspended from this a box, or car (Pl. X, *B*), large enough for the hydrographer to sit or stand in while using the meter. In this box, out of the reach of the floods, the hydrographer can propel himself from side to side and can lower his meter to any desired depth beneath the surface.

The accompanying illustration (Fig. 19) has been prepared to illustrate the operations of measurement of velocity by this method. The drawing represents a river flowing toward the reader, and ending abruptly, as though cut off to give a section showing the surface and bottom of the stream. Across the river at this point is stretched a steel cable suspended from posts, each end of the cable being carried over the top of the post and continued to an anchorage buried deeply in the soil. The cable is drawn tight by means of a turnbuckle between the anchorage and the supporting post. On this cable a small car is hung by means of two pulleys, which allow easy motion forward and back. Beside the cable, or immediately above it, is a small wire carrying at intervals of ten feet a series of tags marked ten, twenty, thirty, etc.; these serve to give the distance from some fixed point on the shore. On the left side of the view on the bank of the river, is shown a stick of timber inclined at about

the slope of the shore. This has been marked to vertical feet and tenths, and is the gage upon which record of the daily height of water is kept.

The curved, dotted lines of the figure are intended to show points of equal velocity; the points forming an oval-shaped figure in the centre of a section of the stream are those having the same speed, this being greater than that shown by the

FIG. 19. — Method of measuring a river from a car suspended from a steel cable.

curved line which surrounds it; and this in turn having greater speed than the points lying outside of it, and so on, the speed of the water decreasing from a point beneath the centre out toward the banks. The bottom being irregular, there is shown on the right-hand side a portion of the stream where the velocity increases somewhat and again diminishes toward the shore.

The vertical lines on the section divide the river into compartments ten feet in width, these being located by means of the tagged wire. The depth

A. SUPPORTS FOR SUSPENDED CAR.

B. METHOD OF USING METER FROM BOAT.

of each of these compartments is ascertained by sounding, by means of a cord and weight, or by a stick or pole. The velocity is also measured near the centre, this being taken as the average for the whole compartment. The velocity thus obtained by means of the current meter and computed in feet per second is multiplied by the average depth of the compartment and by its width, the result being the discharge in cubic feet per second. The sum of all the measurements gives the total flow of the stream.

The methods of using the meter, or rather places at which it is held in the cross-section, vary somewhat according to the nature of the stream to be measured. In an artificial channel of regular size, particularly in a wooden or masonry flume or conduit with flat bottom and straight sides, there is usually less variation in the velocity of different portions of the section. Thus, the number of observations with the meter may frequently be reduced without decreasing the accuracy of the work. In the accompanying figure (20) is shown the cross-section of a wooden flume, this being considered as divided into four portions or compartments. In that on the left-hand side, numbered 1, dotted lines and arrows have been drawn to indicate one of the methods of using a current meter. Starting at the top, the meter is lowered slowly along the side of the flume to the bottom, then carried diagonally upward to the top, then vertically downward

to the bottom and diagonally across to the point of beginning. The instrument is moved with a slow, steady motion. The number of seconds required to complete this circuit is usually from fifty to seventy-five, record of these being kept by a stop-watch, and the number of revolutions of the meter being counted. This process and its modifications are sometimes known as measurement by integration, it being assumed that the average velocity of the water is obtained by the meter as it is moved from place to place.

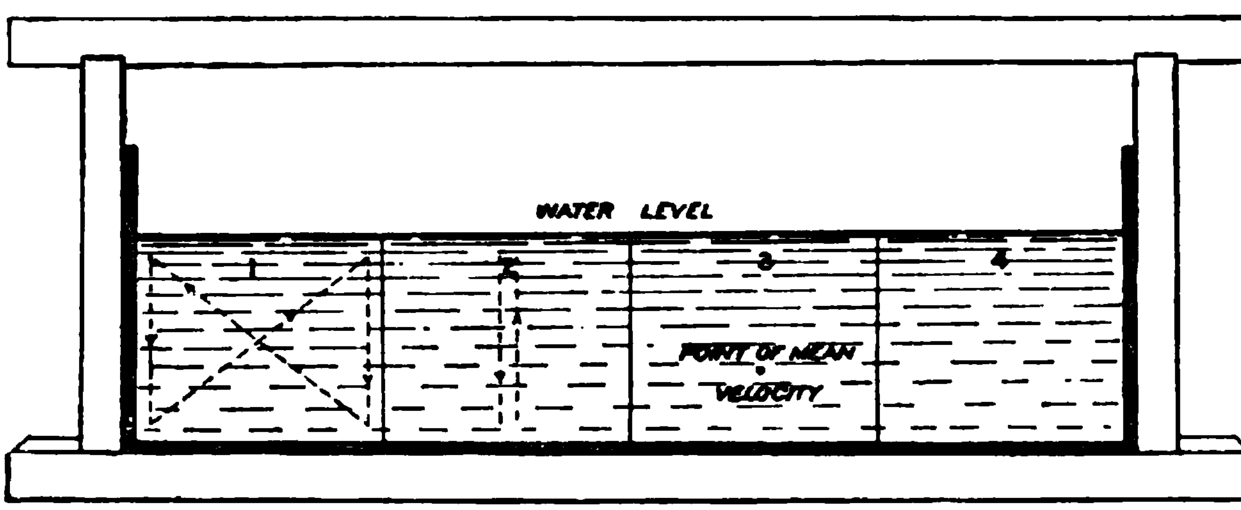


FIG. 20.—Section of flume illustrating methods of measurement.

In the division numbered 2 the course of the meter is indicated as being moved slowly from the top to the bottom, thus integrating the velocity through the centre of the section, it being considered that at a distance from the side of the flume a fairly uniform motion of the water takes place. A third method of obtaining the velocity is that shown in the division marked 3, where the meter is held steadily for fifty or one hundred seconds

at the point of mean velocity, this being approximately three-fifths of the depth below the surface. The speed at this point has been found by experiment to be usually equal to the average for the entire division or compartment.

It is usually preferable in streams with rough sides and bottom to make observations of velocity at various points across the section and near the top and bottom, as it is not safe to rely upon the water following any arbitrary rule deduced from other streams. There are occasionally pools of stagnant water near the edges or in deep holes, and these can be discovered only by a well-distributed series of velocity measurements at definite points.

Weirs.

The methods above described are what may be termed direct forms of measurement, since they involve ascertaining the simple elements of width, depth, and velocity. There are, however, other methods which arrive at the total flow by the application of principles and formulæ derived from experiments. In these methods the velocity of water is estimated as it passes over or through some regularly formed channel or aperture; for example, over the crest of a dam or through openings cut in it. A dam, whether in a large or small stream, so constructed that the water passes over it or through a regular section, usually with decided fall, is termed a weir. The weir may be totally

submerged or its sides or ends may project above the water, narrowing the channel. The term is applied, on the one extreme, to the great masonry structures built across large rivers for the purpose of regulating the channel, and on the other extreme, to a board placed across a small brook or ditch, with a notch or opening cut in it, to permit the regular flow of water for the purpose of measurement.

Elaborate and careful experiments have been made with weirs of various forms and dimensions, to determine the rule or law of velocity of the water flowing through openings of given size and shape. From the facts thus obtained formulæ have been derived which are applied to streams of considerable size, as well as those comparable to the ones upon which the experiments were tried. The accompanying illustrations show two classes of weirs. The first (Pl. XII, *A*) is across Genesee River, New York, taking the full flow of that stream in high and low water. The second (Pl. XII, *B*) is on Cottonwood Creek, in Utah.

The essentials of a weir are that the water shall be partially stilled and flow gently with uniform current toward the edge. Above this edge there should be deep water, so that the currents may approach without disturbance. On the lower side there should also be a free fall. There are a number of technical requirements to be observed according to the formula to be applied; that is to say,

A. WEIR ON GENESEE RIVER, NEW YORK.

B. WEIR ON COTTONWOOD CREEK, UTAH.

for a sharp-crested or flat-crested weir, or for one with end contractions, certain precautions are to be observed. In order to secure accuracy, attention must be given to all of these details, that they may conform to the conditions of the original experiments from which the rules were derived.

The accompanying figure (21) shows a small weir placed in a running stream, ponding water some-

FIG. 21. — Ordinary weir in a small stream.

what by contracting the channel. As the water approaches the sharp edge over which it falls the stream contracts, so that to ascertain the exact height of the water above the horizontal crest over which it falls it is necessary to drive down a peg three or four feet back from the crest to the exact level with the edge of the weir, and to measure from this peg up to the water surface. This

gives the height of the water on the weir; the depth of water above the weir should be at least twice this height. The weir should be placed at right angles to the current of the stream, and the water should be brought as nearly as possible to rest, passing with free fall over the crest, and with a width at least three times the depth. By carefully observing certain precautions, and applying suitable formulæ or rules derived from experiment, it is possible to ascertain the flow of a stream with an error of only 1 or 2 per cent. Computations of discharge can be avoided by using tables prepared for weirs of different size and form, a number of these having been printed as standard books of reference for the use of engineers.

Many of the more important rivers of the United States are used, in part at least, for water power, and dams have been built across them, raising the water and ponding it for many miles. Occasionally the dam of one water power is placed near the upper end of the slack water caused by the dam below, and thus the free flow of the river is impeded and artificial conditions are created, so that ordinary current meter or float measurements are impossible. In such cases the discharge of the stream can be ascertained only by using the dam as a measuring weir and by various indirect methods. It is necessary to know the amount which passes through the water wheels, out of the waste ways, as well as that flowing over the crest of the dam

in times of flood. To do this requires a large number of observations. The amount of water used by each wheel must be known, and the number of hours during which the wheel is operated each day, the wheel being considered as a water meter. The sum of the quantities used by the wheels can thus be obtained, and to this must be added the amount flowing over or through the dam. Each of the openings must be measured, and the amount which escapes over the top computed by considering the dam as a weir. The matter is further complicated by the fact that many mill dams, especially those built of logs or timber, are full of small leaks, permitting a quantity of water to pass through or beneath them, the amount of which can only be roughly approximated or guessed. It is possible, however, by these somewhat roundabout methods to obtain a very fair estimate of the discharge of a river, — one which is of value in all practical considerations.

CHAPTER IV.

CONVEYING AND DIVIDING STREAM WATERS.

DIVERSION FROM THE STREAM.

THE greater part of the water used in irrigation is taken from the river or creek by natural flow or gravity. The cost of lifting or pumping water is usually too great to be profitable for the production of ordinary crops, and therefore most irrigation systems must be planned with reference to the relative altitude of the lands to be irrigated and the source of water.

The streams issuing from the high mountains descend with rapid fall toward the lower valleys, where, as a rule, the slope is less and the water moves more slowly. The lands to be irrigated in the valley are, for the most part, along the river, but at a higher elevation than the stream which they border. They are, however, in part at least, lower than the water farther up-stream; and if a canal or ditch is begun on a gentle grade above the head of the valley and carried out along the banks of the stream, it can be kept at a higher elevation than some of the valley land. In the

narrow gorge or canyon above the valley the stream may be falling at a rate of 10 feet per mile. Water will flow in the ditch if a fall of only 2 feet per mile is given to it. Starting on this grade from the river, at the end of the first mile the water in the ditch will be 8 feet above that in the river, and at the end of the tenth mile will be 80 feet higher, and will thus cover all land which is less than 80 feet in altitude above the stream at this locality.

In the accompanying diagram (Fig. 22) the letter *A* is at the head of the valley and *B* at the lower end. The river, *E*, flows with winding course from *A* to *B*, with agricultural land on each side sloping gently toward the river. Some point, *C*, back from the river can be found which is lower than *A*, and a canal line on a gently descending grade, less than that of the river, can be taken out from *A* and beyond *C*, following the contours of the side slopes. The land between the canal and the river is lower than the canal, and lateral or distributing ditches can be taken out toward the stream. These can be constructed directly down-hill, or, if the slopes are too steep, can be carried off diagonally.

In planning an irrigation system, it is usual to begin at the highest point of the tract of land or valley to be irrigated, and run a trial line on a slightly ascending grade (a foot, more or less, to a mile), following this line as it meanders in and

out along the slopes, and continuing it through the upper end of the valley and into the canyon from which the stream issues, until the trial line finally reaches water level. Frequently it happens

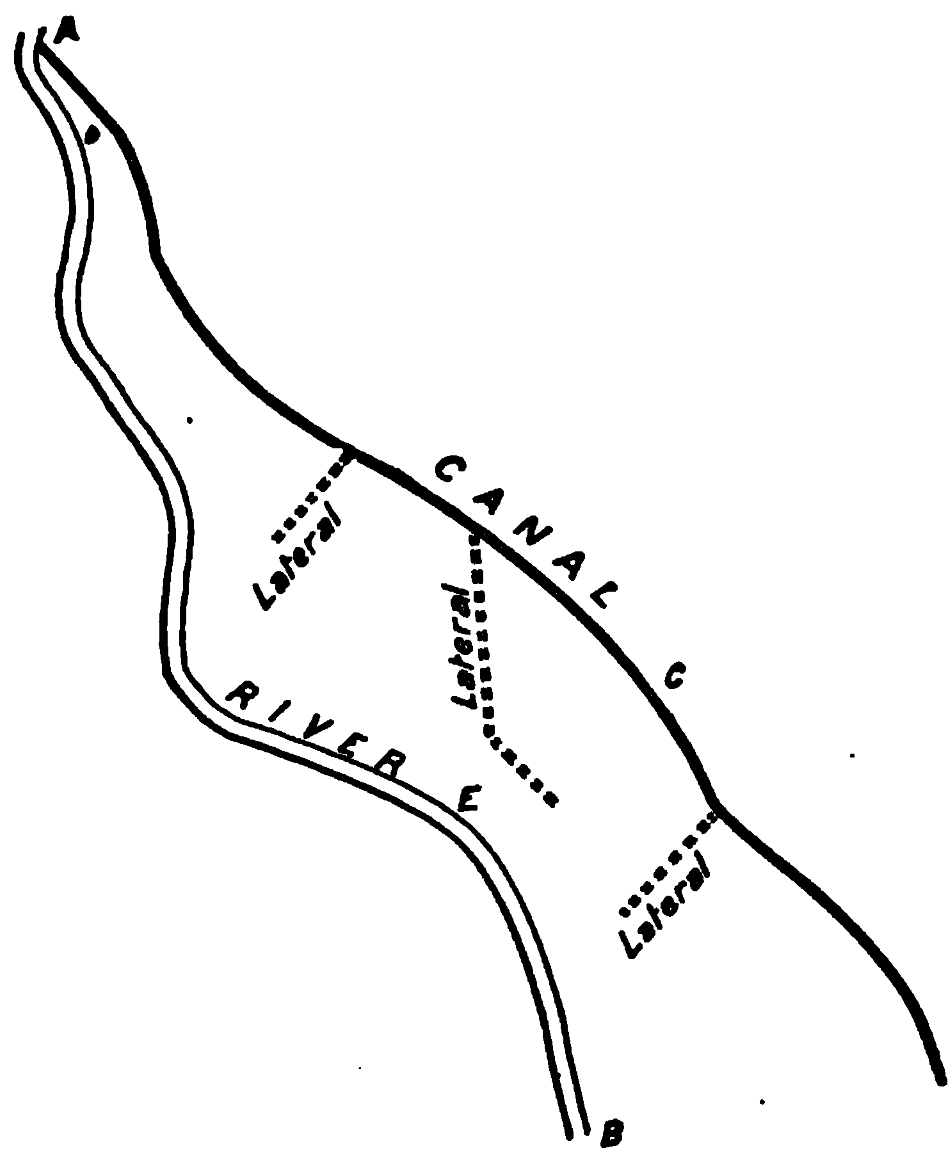


FIG. 22. — Diagram showing method of diverting a canal from a river.

that such a line will wind around bluffs and rocky places where ditch construction may be impossible. In such a case a higher or lower line must be taken. If lower, it is apparent that the higher points in the valley cannot be reached by the water, and it may be necessary to leave unirrigated above the ditch a considerable portion of the fer-

tile land. Thus it sometimes occurs that, even though there is an abundance of water, some of the good land must be left unwatered, as it is impracticable to build a ditch which will reach it.

In the simplest case of laying out a ditch, a farmer takes a straight-edge or board 16.5 feet, or a rod, in length, and tacks on one end of this a projecting block or peg one-half of an inch or an inch in height. When this board is placed horizontally, the lower projecting point will give a fall of one-half of an inch or an inch to the rod. Beginning at a given point, one end of the straight-edge is placed on a stake driven flush with the surface of the ground, and the other end, having the projection upon it, is swung around until it strikes the surface. A stake is driven in here, this stake being lower than the first by an amount equal to the height of the projection or peg. The operation may be reversed if the laying out of the ditch is begun at the lower end. In this way stakes are driven into the ground at intervals of a rod, marking out the course of the ditch upon a slightly ascending or descending grade according as the work is begun from the lower or upper end.

The accompanying figure (23) shows an effective form of levelling device used by irrigators. It consists of a straight-edge or board, from the ends of which pieces extend diagonally upward to form a support for a plumb bob. This is adjusted so that when the straight-edge is horizontal the plumb

bob will fall opposite a fixed point. The same results can be obtained by using a carpenter's level, but the device shown can be constructed by any person of ordinary skill, and will suffice for laying out ditches for irrigation or drainage.

The ditch having been staked out in the manner above described, or better by means of surveying instruments, a furrow is ploughed along the course,

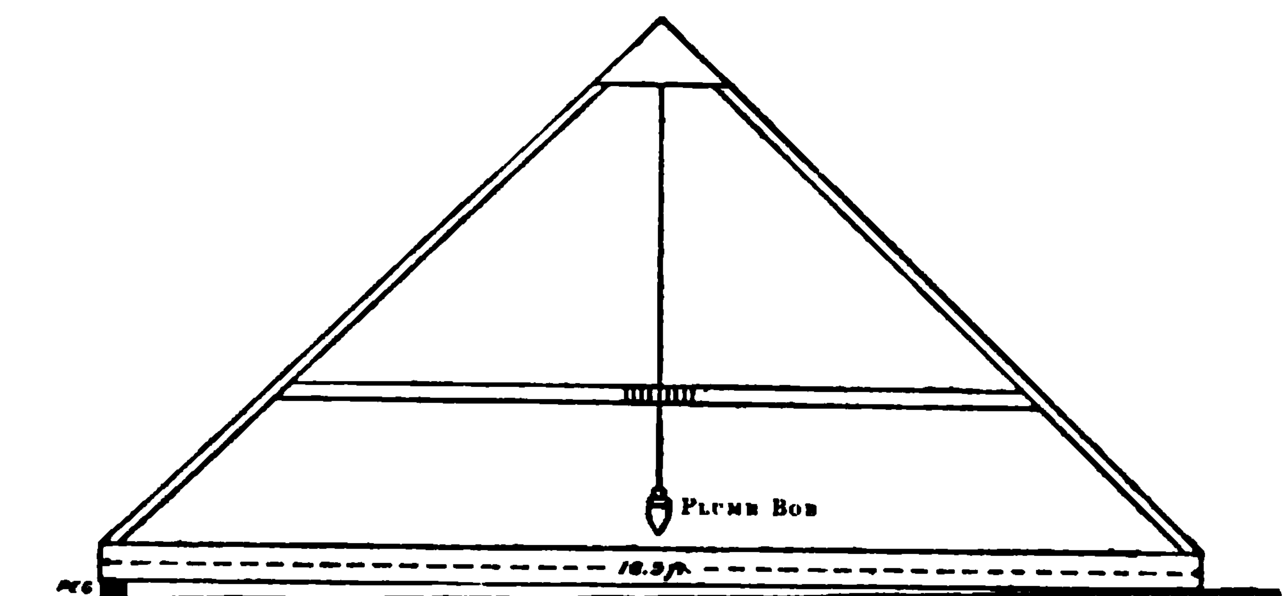


FIG. 23. — Levelling device for laying out ditches.

and the earth thrown out by shovels or scrapers (Pl. XIII, *A*). Near the upper end of the ditch it may be necessary to blast away the rocks, and at intervals along its course depressions must sometimes be crossed by means of wooden flumes. As far as possible, however, ditches are carried up into and around depressions in the surface of the ground, in order to avoid building these wooden structures, since they decay rapidly and are sources of considerable expense. (See Figs. 36 and 48.)

A. DIGGING A DITCH FROM A RIVER.

B. THE FINISHED DITCH.

For the purpose of digging large ditches or canals, a number of farmers usually combine, forming an association which may be incorporated. Ownership is usually based upon the proportion of labor contributed by each member, and this in turn is determined largely by the amount of land owned and to be irrigated by each person. These associations may be simply partnerships without any written agreement, or may be formally organized with constitution and by-laws, and be incorporated under the laws of the state. Frequently stock is issued, each share entitling the owner to receive a certain amount of water from the ditch, or a definite proportion of the whole amount available at any particular time. Sometimes these shares specify the time of day, so that one man receives the entire flow of the main ditch or a lateral from six o'clock in the morning until noon, and his neighbor, being entitled to less water, receives the entire flow from noon until two in the afternoon; and so on throughout the day and night.

These associations or corporations elect their own officers and manage their affairs in the same manner as any other business concern. The most important official, however, after the treasurer, is the person charged with the management of the canal. He is usually known as the "watermaster" or "ditch-rider"; or, in Spanish-speaking communities, as majordomo or zanjero, from the word "zanja" (usually called sankha), the Spanish term

for irrigation ditch. It is his business to see that all stockholders or owners receive a fair amount of water, using various means for measuring or dividing it, as described on a later page.

The greater number of ditches and canals now in use within the arid region have been built by individuals and associations of this character. In a relatively few instances large works have been constructed by corporations issuing stock to persons who were not landowners, and borrowing additional capital upon bonds. Several canals have been constructed in this way, but as a rule these have not been financially successful, and development is not continuing along this line.

DISTRIBUTION OF FLOW.

The pioneer, coming to a new portion of the arid country, first sought a stream from which water could be diverted upon arable land. As a rule he laid claim to the whole flow and built a ditch, small at first, taking only enough water to supply the land which he could cultivate during the first year or two. From time to time, as more land was brought under irrigation, the ditch was enlarged by being widened and deepened, more and more water being taken from the stream as needed. In the case of associations of farmers, the same course has usually been followed, the ditch or canal being at first small and built in the quickest and cheapest manner possible, and then

gradually enlarged to take a greater and greater proportion of the water in the river.

Soon after the first settler or association took out water in a ditch, others would begin similar works a few miles above or below the first, each in turn generally claiming all the water to be had at the particular point where the head works were located. If the stream is of considerable volume, sufficient to fill all of the ditches, no difficulties arise; but sooner or later the increasing size and number of ditches and canals result in diminishing the flow in the river to such an extent that it becomes dry, and water does not reach the ditches farthest down-stream. This scarcity of water first becomes apparent during the latter part of the crop season, in July and August, when the streams, as shown by Fig. 16 (p. 65), are lowest and the need of water is greatest.

It usually happens that the ditches lowest down-stream are those which were built first, and which under the customs prevalent in arid regions are entitled to priority of right to the use of the water. The farmers under these lower ditches, seeing their crops wither and orchards which have reached maturity die for lack of water, are tempted to take desperate measures, and going up-stream, forcibly close the head gates of the upper canals, tear out dams in the river, and let down needed water for their farms. Thus has come in some parts of the arid region, a time when, owing to scarcity of water,

lawlessness has prevailed, and every man has endeavored to obtain for his own crops as much as possible of the scanty supply.

The necessity for rules and regulations governing the division of water from the streams early became apparent in all localities where development has proceeded to any considerable extent, and various schemes have been devised for such regulation. Along some of the rivers, the farmers and canal companies, becoming weary of the frequent controversies among themselves, have voluntarily joined together, and after much debate and experimenting have finally agreed upon rules by which a division of the water has been made. Where these matters could not be thus settled, court decisions have been obtained. Such, for example, has been the result along many of the streams of California, the arrangements being complicated and difficult of ready comprehension by the stranger, but well understood by the irrigators themselves and all based upon experience and local needs.

In some parts of the arid region the states have undertaken the regulation of disputes, and have created special boards or tribunals to consider the matter and apportion the water. For example, in Colorado, where the state is divided into districts, each embracing a single stream, the regulation of the waters is intrusted to state officials known as commissioners. The districts are grouped to-

DREDGE CUTTING LARGE CANAL OF CENTRAL IRRIGATION DISTRICT, CALIFORNIA.

gether to form divisions corresponding to the principal river basins. Each division is under the charge of a superintendent, who supervises the work of the commissioners. Superintendents, in turn, are under the state engineer. It is the duty of these officials to regulate the head gates in time of scarcity, carrying out the decrees of the state courts, cutting off water from the new ditches in order that the older priorities may be supplied, following the decrees made by the courts as to the order of priority and amount of water to which each ditch is entitled.

In Wyoming the state engineer is empowered to ascertain the amount of water flowing in the stream, and with the superintendents forms what is practically a court for the hearing of cases and the adjudication of claims to the water, the principal facts having been ascertained by observation and measurement in the field rather than by testimony of interested parties, as in Colorado. This has sometimes been regarded as theoretically the best method; but practice has raised some doubts as to its applicability in states where developments have proceeded farther.

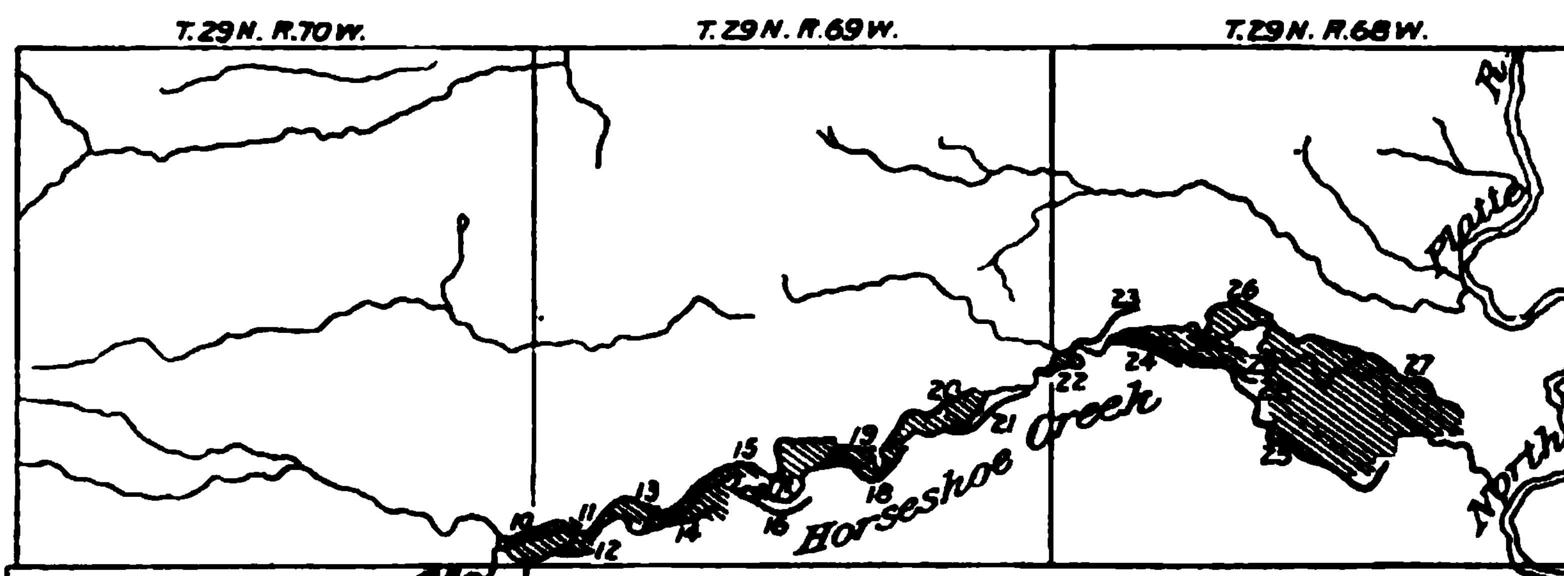
While there is little uniformity among the different states as regards the control and distribution of water, there are certain underlying principles which are discussed on page 286 under the head of Irrigation Law; and, more than this, there is a gradual tendency toward evolution along lines

which experience has shown to be best suited to American conditions. The first stage of development is the construction of small ditches, each conducting water from streams sufficiently large to supply all needs. The next stage is where the increase in number and capacity of the ditches has resulted in scarcity of supply and in competition among the claimants for water. The third stage is one of mutual adjustment and division according to court decrees or agreements reached by arbitration. The next stage, one which is being gradually reached, is the adjustment of interests so as to allow an apportionment of water in such a way as to increase its economical use. For example, instead of dividing the water strictly according to priority and thus wasting considerable portions in forcing it down the stream to lower ditches, the scanty supply is so distributed as to give the greatest benefit to the greatest numbers.

The last stage of evolution of water distribution is that in which, all or the greater part of the interests being mutually adjusted, the united efforts are directed toward water storage and conservation of the supply by building reservoirs and by adapting the methods of irrigation to suit the fluctuating quantities.

The accompanying figure (24) illustrates the manner in which ditches have been constructed at regular intervals along a stream, taking water out on one side or the other. In this figure the

ditches are numbered in geographical order from the head waters down, and the lands irrigated under them are indicated by shading. The order of priority in the use of water is not that of the position along the stream. For example, No. 22,



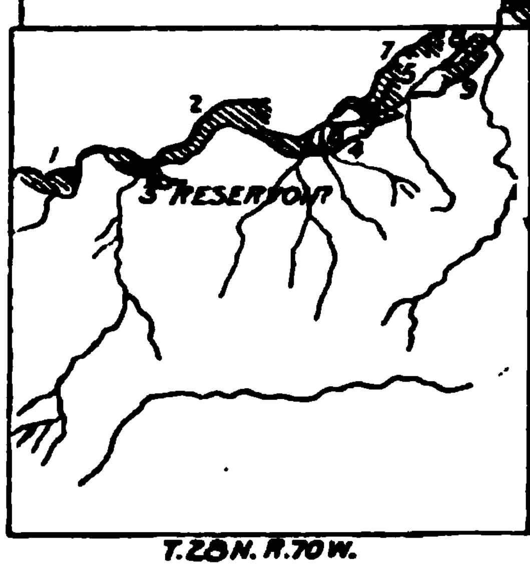


FIG. 24.—Map of ditches along a stream.

near the lower end, may be the oldest, and therefore entitled to the full share of water before all the others, and No. 7 may be the latest, and entitled to water only in times of flood. When, therefore, a scarcity occurs in the river, No. 7 is at once closed down, and then No. 10, if it happens to be the next as regards recent construction, and so on, one ditch after another being deprived of water in order to supply the oldest ditches with the needed amount, until finally, in extreme drought, the ditch first constructed receives the entire flow. With increase of discharge of the

stream, the head gates of the ditches are opened in the order of date of priorities until, in times of flood, all are opened.

After a ditch or canal has received its full supply, or the quantity to which it is entitled, there usually arise among the various irrigators many conflicting demands in times of scarcity, the condition being comparable to the claims made by the canals upon the main stream. In the early days, when there was plenty of water in the river, and the ditch or canal carried more water than was needed, each user took all he chose, flooding his land freely, sometimes drowning out and destroying portions of it, and running the excess over the roads and neighboring grazing land. With the gradual widening of the cultivated area, the need for water has increased, and attempts have been made to check the waste; but the older irrigators, accustomed to the lavish use of water, have been loath to restrict themselves, even though it has been demonstrated again and again that better results could be had by using less water.

It has usually been found necessary for the irrigators to appoint or elect one of their number to serve for a season as watermaster, and to apportion to each claimant a certain amount of the water, or assign certain days and hours during which water can be used. The watermaster must, when the supply is scanty, go along the canal and see that the various head gates are closed or opened to

A. MASONRY HEAD-GATES OF CANAL.

B. TIMBER REGULATOR.

receive the determined quantity of water, locking these so that they cannot be tampered with after he has left. Often the quantity of water has been settled only after vexatious lawsuits or neighborhood quarrels, and great tact is required to preserve friendly relations during times of scarcity, when some crops must be left to wither under the intense summer heat, in order to save others whose owners enjoy older or prior rights.

DAMS AND HEAD GATES.

At the upper end of each ditch it is usual to construct some device by which the amount of water entering from the river can be regulated. Without this, flood waters would fill the ditch beyond its capacity, overflowing and washing away the banks. In times of low water, also, the stream may fall to such an extent that it must be raised somewhat by a dam and forced into the ditch. At all times it may be necessary to regulate the flow in order to apportion the water fairly to all concerned.

In the case of the simplest ditch, a small dam of brush and stone, illustrated in Fig. 25, is usually built diagonally into or across the stream bed as the water becomes low in the summer, and this is made tight by means of sod and earth. Such a dam is usually washed away by high water, but can be replaced at small labor and expense. More permanent structures are sometimes built of timber

or masonry, especially in the case of works constructed by large associations or corporations. These dams, intended to resist the destructive action of floods, must be solidly constructed and carried down to bed rock.

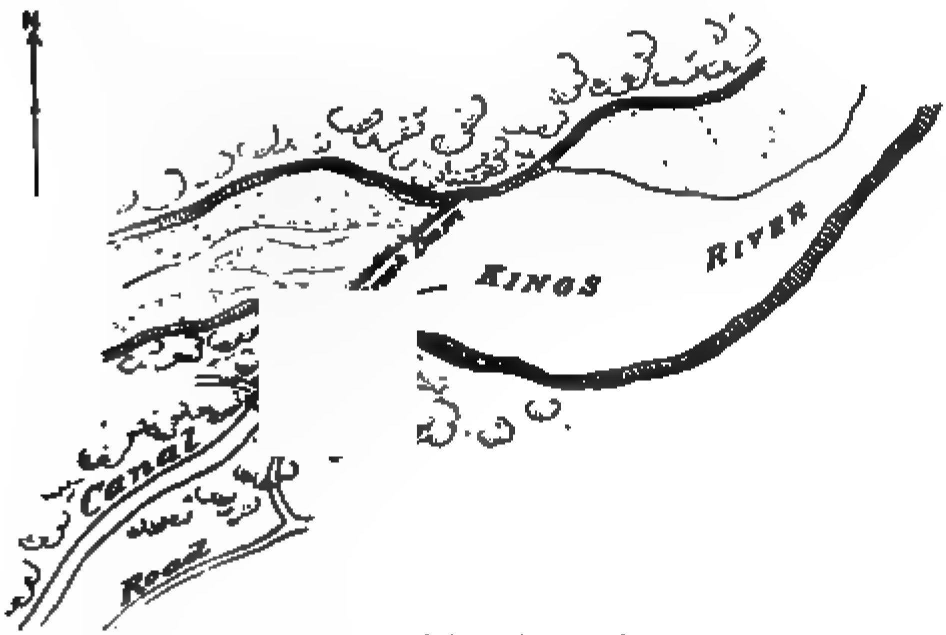


FIG. 25.—Plan of diversion works in river.

The temporary brush dams are cheaply constructed and suffice for most of the smaller ditches, and even for some of the larger canals. They possess the advantage that whenever a destructive flood occurs, modifying the channel, they can be rebuilt to suit the new conditions, the head of the ditch being extended, or located at a point where-ever the dam can be most cheaply or effectively constructed. Sometimes, as shown in Fig. 26, two canals head near each other, and the temporary dams can be modified from time to time to divert

the water in the river according to the volume available.

Near the head of a ditch or canal is usually placed a head gate, or regulator. This consists of a suitable framework of plank, firmly bedded in the earth or rock, and containing one or more openings, each of which can be closed by a gate

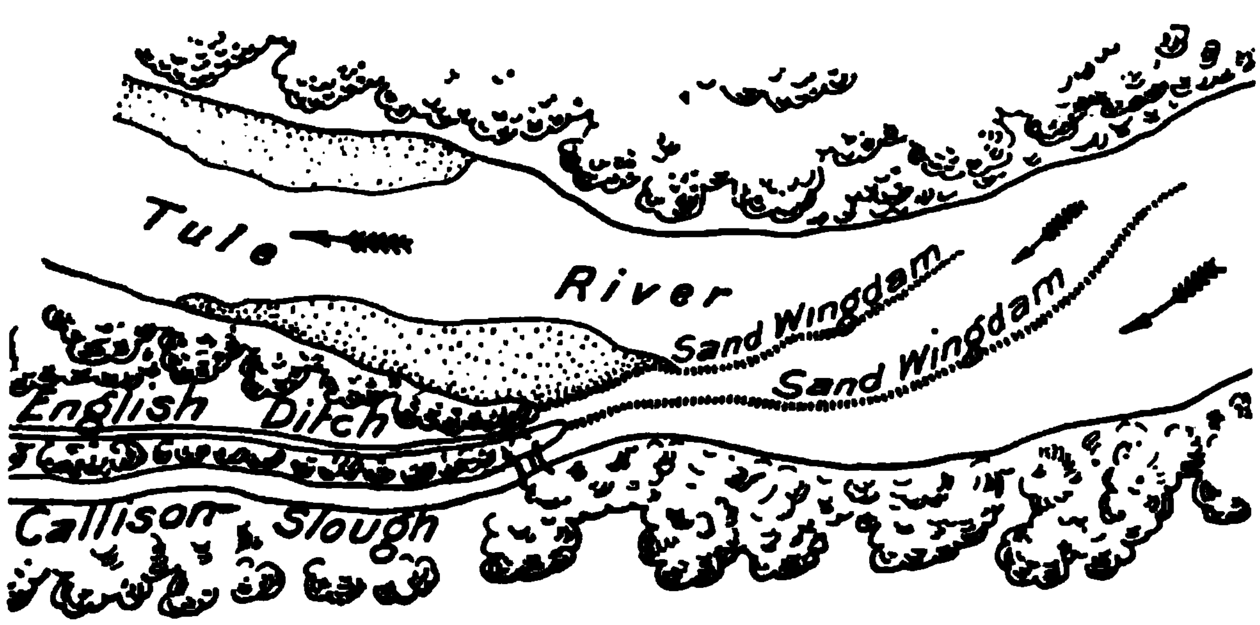


FIG. 26. — Brush dams of canals heading near each other.

sliding vertically. The water enters under the gates, the quantity being controlled by raising or lowering them. On the better-built canals permanent head gates are sometimes constructed of masonry, as shown by Pl. XV, *A*. The relative situations of the canal, dam, and regulator, where the conditions are favorable, are shown on Fig. 27.

The adjustment of these head gates is a matter of considerable importance in taking water from the river, and for large canals it is necessary to have a watchman stationed near the head, in order

that the gates may be raised or lowered, according to the amount in the river and the quantity apportioned to the canal.

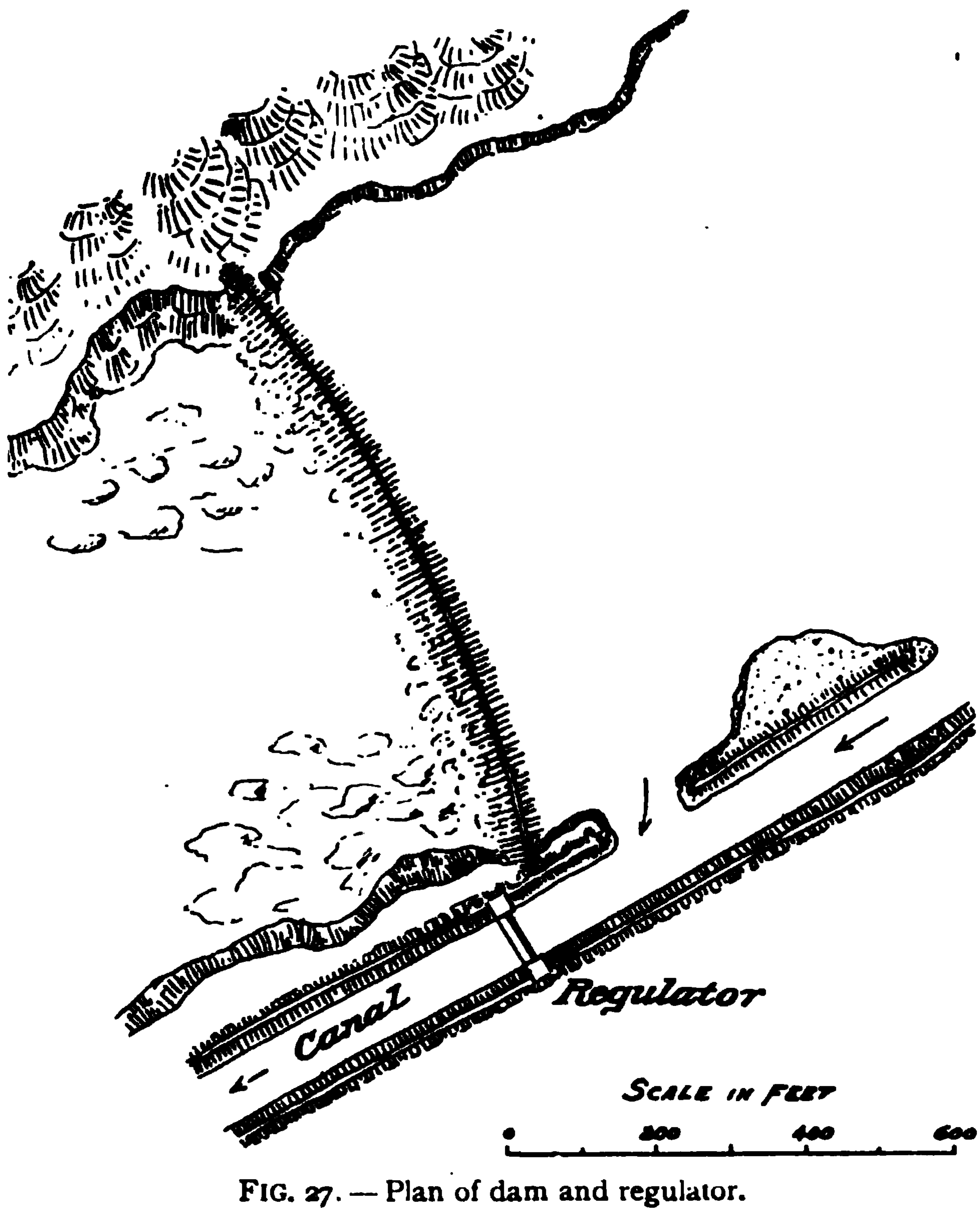


FIG. 27. — Plan of dam and regulator.

The accompanying drawing (Fig. 28) shows the method of construction of one of the small timber head gates, or regulators, such as are used at the

head of small ditches leading from the stream or from some large canal. These are built of plank, each end being made flaring to meet the sides of the ditch and to form a firm junction with the

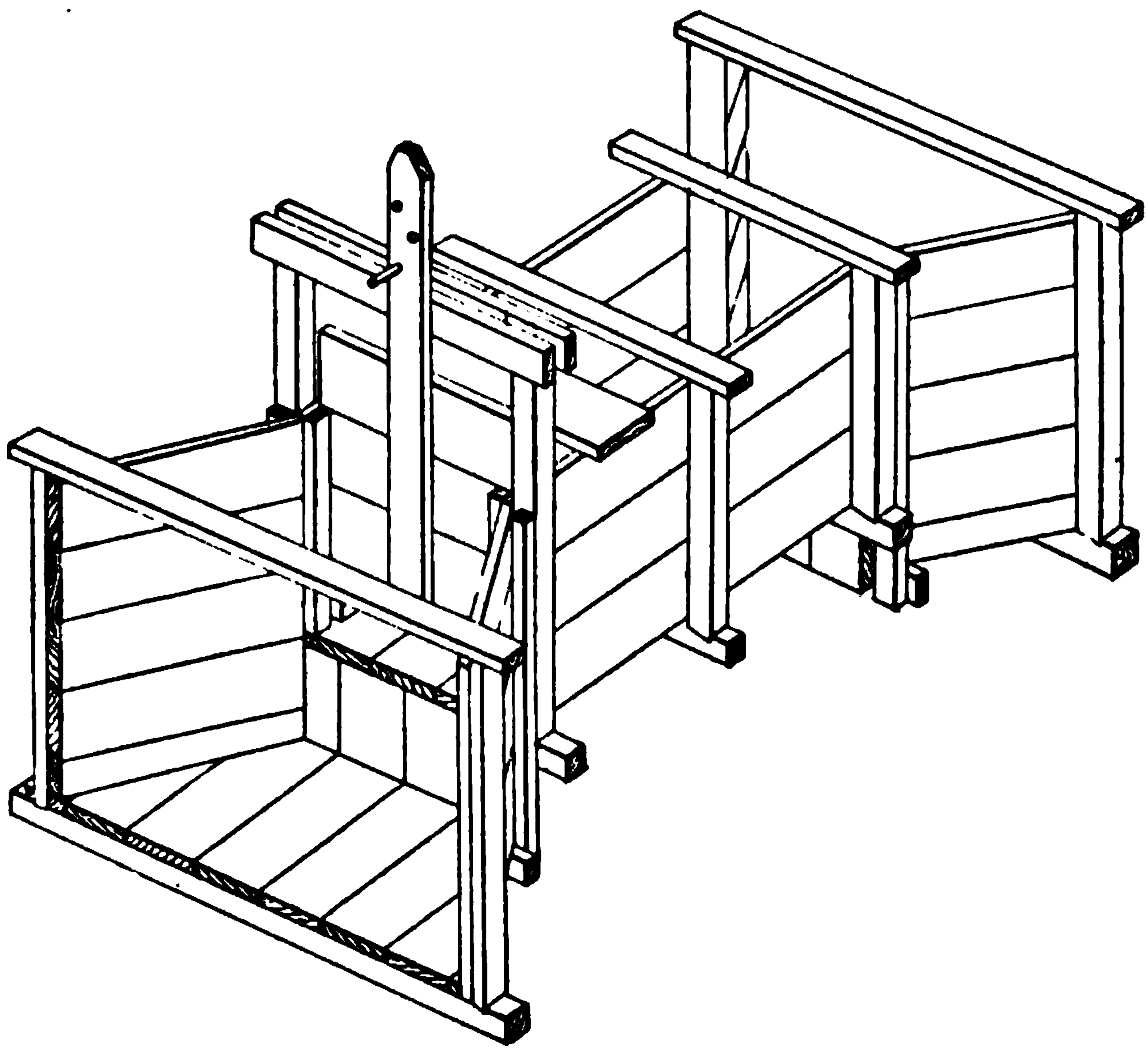


FIG. 28.— Details of small head gate.

earth. It is, of course, important to pack clay and impervious material around the head gate so as to prevent leakage, as a tiny stream working its way through the earth will quickly be enlarged and endanger the whole structure. Various forms of head gates are shown on Pls. XV and XVI.

MEASURING DEVICES OR MODULES.

After water has been received into a canal and at various points along its course to the fields of the irrigators, there frequently arises the necessity of making measurements of the volume, or of dividing the flow proportionately among the users. The methods employed are in general similar to those in river measurements, described in preceding pages. The quantity of water is, however, often so small, and the means at hand so restricted, that different ways are occasionally adopted. The persons whose business it is to divide the water rarely have instruments, such as a current meter, and their knowledge of hydraulics is too limited to enable them to make measurements of any considerable accuracy. They usually judge of the amount of water by its appearance, at most measuring the width and depth, and guessing at the velocity, or not taking it into account. There is thus little attempt at accuracy, and, in fact, absolute quantities are not often obtained, but rather proportional parts of the flow. An irrigator usually receives a quarter or one-tenth of the water in the ditch rather than a certain number of gallons or cubic feet per second. Thus the measuring boxes or flumes are generally made with the idea of taking a certain proportion of the whole amount of water irrespective of the volume.

One of the simplest devices for apportioning

A. REGULATING OR MEASURING DEVICE NEAR HEAD OF CANAL.

B. DISTRIBUTION BOX ON FARMER'S LATERAL.

ditch water is shown diagrammatically in the accompanying plan (Fig. 29). The water, flowing toward the left, is divided by the partition marked *A*. The water passing on the left-hand side of the partition *A* is conducted off by a side channel or lateral, while that flowing on the right-hand side of *A* continues in the ditch. This partition *A* may be movable, so as to divert different quantities of water at various times, or may be fixed, if it is understood that a certain proportion of the water is always to pass out of a lateral at this point.

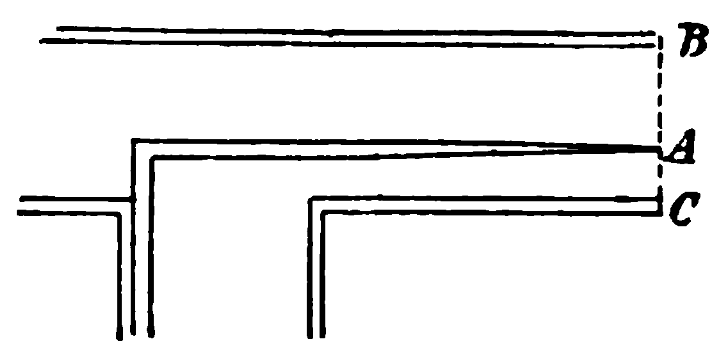


FIG. 29.— Plan of device for dividing water.

If the partition *A* is in the centre of the stream, equal amounts of water will be diverted on each side, except as this may be affected by the retarding influence of the channel beyond. In the condition shown in the diagram, the right-angled turn would probably cause a slightly less amount of flow on the left-hand side than on the right-hand side, where the channel is straight. If, as shown in the drawing, the partition *A* is one-third of the distance across the channel, the amount diverted on the left side will probably be a trifle less than one-third of the whole amount, because of the increased friction in the narrower channel, and also because of the right-angled turn beyond. Other

forms of boxes for dividing water are shown on Pl. XVI.

The devices for measuring water flowing in open ditches differ widely from those employed for measuring in pipes, such as those of a city supply, where various forms of water meters are utilized, nearly all of these requiring a decided pressure and rapid flow. The water in irrigating ditches has usually only a trifling fall, and it is not possible to obtain a head or pressure of more than a few inches. Any measuring device, to be generally successful, must be so constructed as to pass a considerable amount of water flowing at low velocity and with little fall or loss of head. An apparatus of this kind is generally known as a module, the name being derived from Italian usage. The term has not come into general use in the United States, but the measurements of water from ditches are usually spoken of as being made through boxes, flumes, or over weirs. The device in use which may be termed "module," and the one most generally employed, is that for measuring the miner's inch.

This unit, the miner's inch, is the one most used throughout the West in speaking of quantity of water. Irrigators frequently state that they receive so many miner's inches, or that to irrigate ten acres it is necessary to have 8 miner's inches. The term, although common, is not definite, the actual quantity known as a miner's inch differing according to the method of measurement.

It is comparable to the local usage of the word "shilling," which has been commonly used in New England to mean 16⅔ cents, while in New York it has been equally well known as 12½ cents. So the miner's inch in California may represent a fiftieth part of a second-foot, and in Arizona a fortieth part.

The miner's inch is also often confused with the sectional area of a flowing stream, or even with the number of cubic inches per second. In Utah, for example, a stream 20 inches wide and 3 inches deep has been incorrectly described as discharging 60 miner's inches, because the width multiplied by the depth gives this number of square inches. The term, although indefinite, has entered so largely into popular usage that it cannot be easily abandoned, and it may be retained to advantage if defined as a certain definite part of the second-foot.

The miner's inch, as the name implies, is a unit of measurement borrowed from the miners, who first took out the water of flowing streams, conducted it through ditches or flumes, and divided it among themselves. The apportioning of water was found to be most easily done by cutting a rectangular hole in the side of a flume and allowing a certain quantity of water to flow through this aperture. The amount discharged depends not only upon the size and shape of the hole, but also upon the pressure or height of water standing

behind the aperture. That is to say, more water will flow through a hole an inch square if behind this hole the water is standing 6 inches deep, than will be discharged if the water is only 4 inches deep. In the same way, less water will flow through an aperture 10 inches wide and 1 inch high than through an aperture 1 inch wide and 10 inches high, the water standing the same depth above the top of the hole. These simple facts are often overlooked, and the laws prescribing how the miner's inch shall be measured frequently omit necessary qualifications. Exact justice cannot be done to all persons obtaining water by this form of measurement.

The accompanying drawing (Fig. 30) illustrates a simple form of a device for measuring miner's inches. This consists of a flume, in the end of which is placed a partition with an aperture closed by a sliding bar or gate, marked *B*. Water flowing in the flume passes out through the orifice, which in this case is 2 inches high and of a width dependent upon the space opened by the sliding gate. Above the top of the orifice is a plank 5 inches wide. To measure the flow in the flume, the sliding gate *B* is pushed in until the water stands at the top of the end plank and is on the point of overflowing. When this occurs, the pressure or head is exactly 5 inches, and the size of the orifice in square inches gives the equivalent number of miner's inches flowing in the box.

In the example shown, the gate is drawn open 43.5 inches, and as it is 2 inches high, the whole flow is 87 miner's inches.

In case it is desired to measure out a certain amount of water, the gate *B* can be set at this

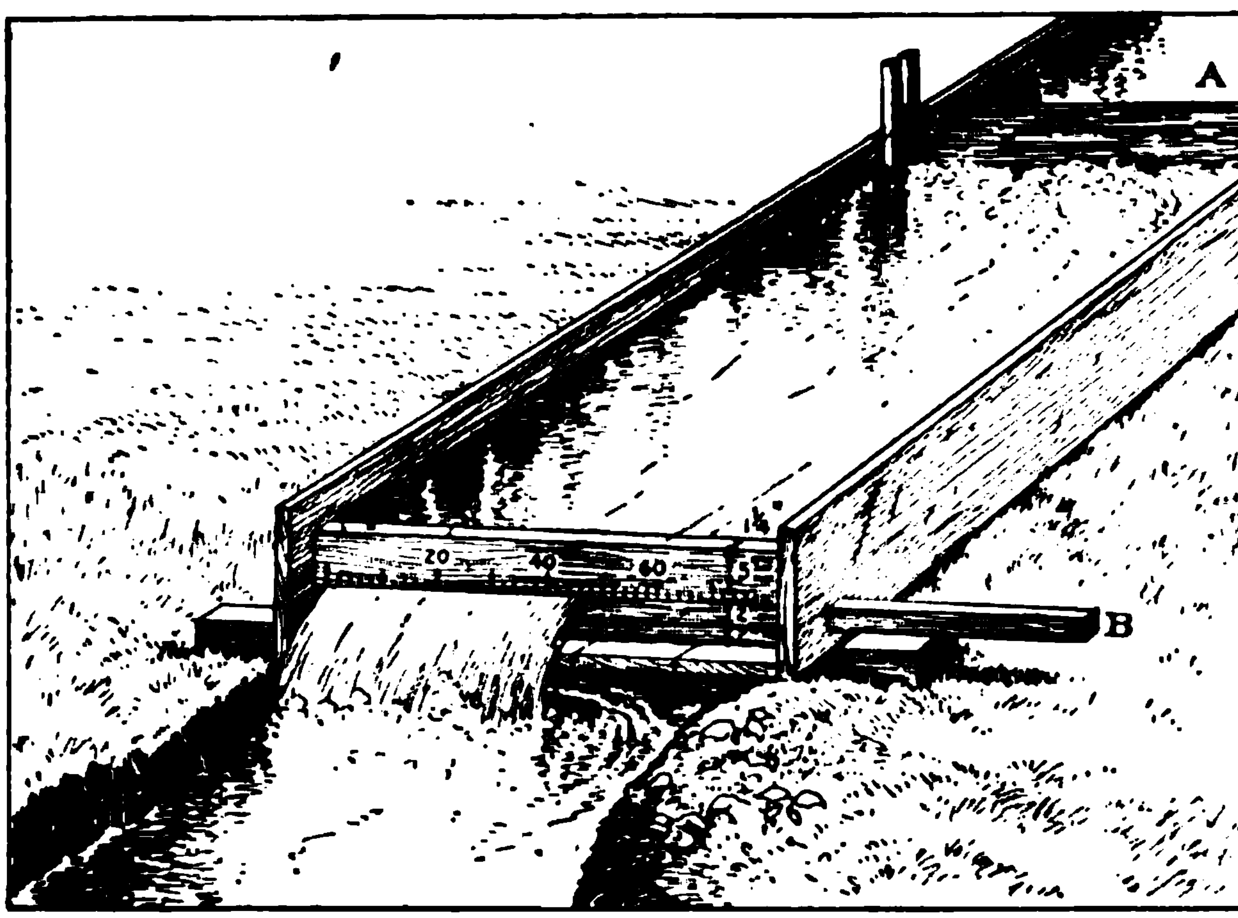


FIG. 30. — Flume for measuring miner's inches.

quantity, and a gate above, marked *A*, adjusted so as to bring the height of the water in the measuring box to the point where it nearly overflows the end plank. In this way small quantities of water can be divided with sufficient accuracy for ordinary purposes. If, however, it is necessary to measure greater quantities, and the orifice cannot be made long enough to accommodate these, it is necessary to make it higher, increasing it, say, from 2 inches

in height to 10; there will then flow through such an orifice more than five times as much water for a given width of opening. Thus, in attempting to measure large quantities of water in this way, serious errors are introduced in favor of the large users of water.

One of the chief difficulties in attempting to measure a constant volume by this apparatus is due to the fact that in many ditches and streams there are occasional and rapid fluctuations of the height of water. When the height increases, a larger amount will be discharged from the orifice; and when it falls, a less amount. To secure a constant head or pressure a number of devices have been made, one of the most interesting of which 's that invented by Mr. A. D. Foote. The measuring box (Fig. 31) *B* is placed by the side of the ditch marked *A*. The water in the ditch is checked by the small gate *D*, and a part is forced to flow through the gate *E*, raised for the purpose, filling the box *B*; the desired quantity escapes through the aperture *F*, into the lateral *G*. Any excess of water entering *B* spills back into the main ditch at *C*, so that a nearly constant head can be maintained behind the orifice *F*.

The method of measuring small brooks or creeks is illustrated by the accompanying figure (32). A stout plank is placed across the stream, held in position by stakes, and made tight by tamping clay on the up-stream side, so that water cannot pass

around or under the obstruction. In the plank is a slot of sufficient size and width to pass the ordinary discharge of the stream. This slot is from

FIG. 31. — Foote measuring box.

4 to 6 inches below the top of the plank, and is closed by a gate or board sliding in front of the slot, and held in position by a small cleat or projection passing through the slot. This gate is gradually closed until the water in the stream is about

to overflow the plank; then the size of the orifice gives the discharge in miner's inches, the exact quantity being dependent upon the head of water, or height above the top of the slot, and its relative proportions.

The standard miner's inch, taking the arid region as a whole, may be considered as the flow through

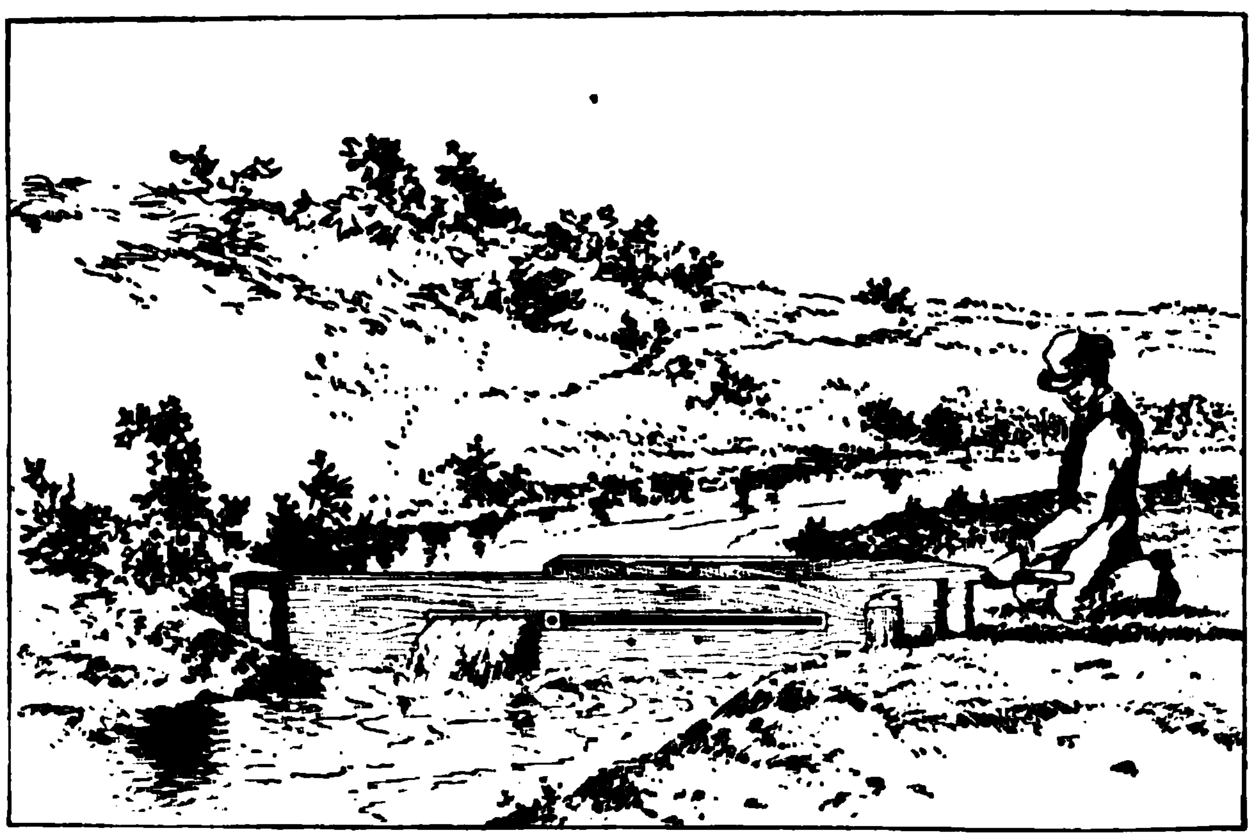


FIG. 32. — Method of measuring miner's inches in ditch.

an orifice 1 inch square with a head or pressure above the top of the orifice of 6 inches. The actual quantity is dependent also upon the thickness of the plank or plate in which the orifice is made, and the character of the edges, whether sharp or square. It has been estimated, however, that the average value of a miner's inch of this character is 1.5 cubic feet per minute, or .025 sec-

ond-foot, — in other words, $\frac{1}{40}$ of a second-foot. In different counties in California it has been found in use to range from .020 to nearly .030 second-foot. In Montana a method of measurement in customary use was through an orifice 1 inch deep with a head of $3\frac{1}{2}$ inches above the top. This has been estimated to furnish .021 second-foot.

The state of California by statute has prescribed that the miner's inch shall be a fiftieth part of a second-foot, and Arizona by court decision has settled upon a fortieth part. In Colorado it has been stated that 38.4 miner's inches made a second-foot, but this figure has been based on a single determination. It is sufficiently exact to state that in this state 40 miner's inches equal a second-foot.

After trying many devices, the engineers and canal superintendents have, as a rule, usually adopted some form of open flume or weir, such as that described on page 99 in connection with the discussion of river measurements. These are least likely to be obstructed by floating sticks or weeds, and are most easily kept in good order. The method of flume measurement consists in measuring the width and depth of water in the flume, and in ascertaining by floats or current meters the velocity for different heights of water. By so doing it is possible to construct a table showing the approximate amount of water flowing in the flume when it is 1 inch in depth, 2 inches, 3 inches, and so on up to the full capacity of

the flume. This method of estimation of discharge is known as rating the flume. When a rating table has once been made, it is usually assumed that the relation between height and quantity of water remains fairly constant.

For flume measurement either one of the structures needed to conduct the water across some depression is used, or short sections of the flume, at least sixteen feet in length, are set in the canal at some designated point especially for the purpose of making the measurement. The floor is smoothly laid and the sides are made either vertical or flaring, the width of the bottom of the flume being the same as that of the ditch both above and below, the cross-section of the flume being as nearly as possible similar to that of the ditch. A scale is permanently marked on the side of the flume, so as to give the depth of water at a glance. The construction of the flume should be such as to avoid all cross-currents or disturbance of the water, the object being to make a portion of the canal in such manner that the sides and bottom will be smooth and permanent.

To insure greater accuracy than that obtained in the ordinary flumes, various forms of weirs are used, these generally having complete contraction at the sides and bottom, as shown by the accompanying diagrams (Figs. 33, 34, and 35). In the first of these (Fig. 33) a rectangular weir is shown, the width of the opening being such as to contract

A. FLUME ON ROCKY HILLSIDE.

B. FLUME ACROSS EARTH IN A SIDEHILL CUT.

the stream on both sides and at the bottom, the distance AB from the bottom of the flume or ditch to the crest of the weir being at least twice that of the height H of the water passing over the crest. With this form of weir it is possible

FIG. 33. — Rectangular weir.

to compute the discharge by use of the simple formula prepared by Mr. James B. Francis, from results of elaborate experiments carried on through many years in the canal built for water power at Lowell, Massachusetts. The discharge in cubic feet per second is 3.33 times the length in feet into the height in feet when the latter quantity has been cubed, or multiplied by itself twice in succes-

sion, and the square root of the cube been taken. Or in other words, the quantity equals $3\frac{1}{3}$ times the length into the three-half power of the height. In this statement the length taken is what is known as the effective length, and not the actual measurement, the measured crest being reduced by one-tenth of the depth of the water H for each end contraction.

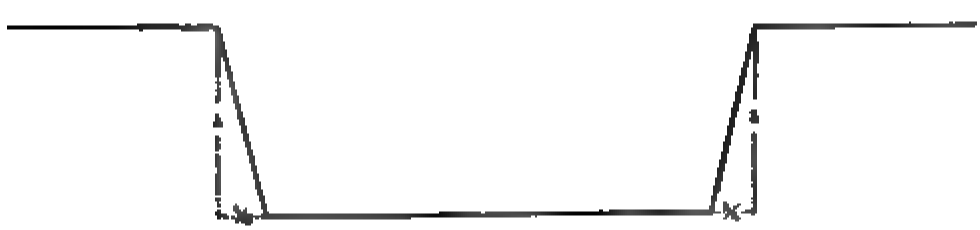


FIG. 34. — Trapezoidal or Cippoletti weir.

In order to obviate the necessity of making corrections for the end contractions of a weir, an Italian engineer, Cesare Cippoletti, devised a trapezoidal weir, or one with sloping edges, as shown in Fig. 34. The effective length in this case corresponds to the actual length of the crest of the weir, thus obviating the necessity of making an

RAISING THE TRESTLES FOR A LARGE FLUME

allowance in the computation for the end contraction.

Weirs of this kind have been placed in irrigation ditches, and the height of water noted from time to time by means of the gage set back from the crest. It is possible at each reading of the height

FIG. 35 — Trapezoidal weir with self-recording device.

of water to obtain by computation, or by a table constructed for the purpose, the amount flowing at that moment. As this quantity fluctuates, it is desirable to have some form of self-recording gage, so that the changes which have taken place can be known. An arrangement of this kind is shown in Fig. 35, where a trapezoidal or Cippoletti weir has

been placed at the end of a short flume and the small recording device arranged on the side of the flume. As the water rises or falls, a float attached to a pencil moves up or down, making a mark on a piece of paper placed upon a cylinder or dial and driven by clockwork. The irregular line traced by the pencil gives a complete record of the height of the water, and from this the corresponding quantities can be computed.

FLUMES AND WOODEN PIPES.

If the ground through which the ditch or canal is constructed were everywhere a gentle slope with well-rounded curves, it would be a comparatively easy matter to dig the necessary channel; but there are often small ravines coming into the main stream from each side, bringing water drained from the highland surrounding the valley. Some of these side channels are very deep and have steep sides, so that the ditch cannot be run around them or continued up one side and down the other. It often happens also that the water of these side channels is utilized by farmers, and must be kept separate from that in the ditch under consideration. Even if the water of the side drainage could otherwise be taken into the ditch, it is usually inexpedient to do so, because local storms often send down these channels great quantities of water, carrying sand, gravel, and boulders, and these deposited in the ditch would fill it up.

SEMICIRCULAR WOODEN FLUME.

In the construction of nearly every conduit of this character it becomes necessary to take water across a depression. This is generally done by means of a flume, or long box, usually rectangular in section. This is supported by a frame or trestle of timber, the lower part of which rests upon the ground. The vertical elevation of such a device is shown in the accompanying figure (36), which gives the general form of the trestle with its cross-bracing, also of the flume, which is shown with the water filling it nearly to the top.

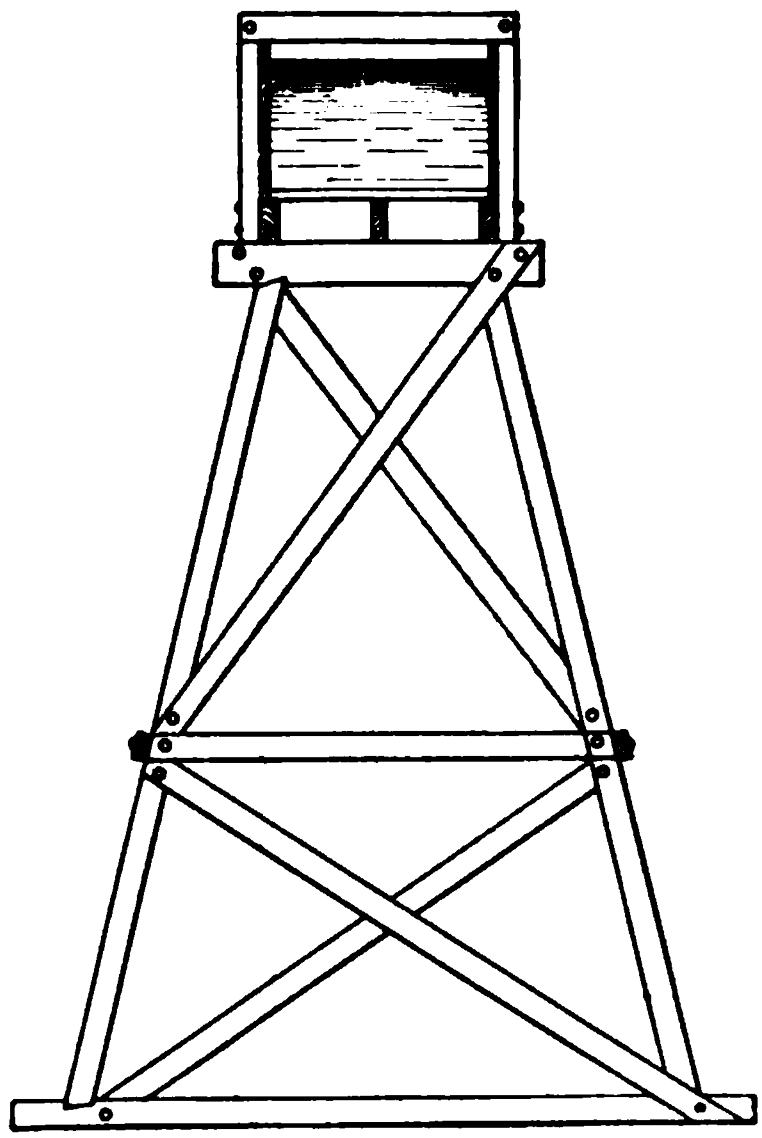


FIG. 36. — Vertical elevation of trestle and flume.

Such flumes are often used across rocky ground where it is impracticable to dig a ditch. This is particularly the case near the head, where the water is often taken out from the river through a narrow, steep-walled canyon. Here the foundation for a flume is prepared along the rocky cliffs, supports being

devised to suit the inequalities of the ground. Plate XVII, *A*, shows one of these flumes built along a rocky hillside.

In some cases, instead of a rectangular, box-like flume, a V-shaped section, shown in Fig. 48, on page 184, is built, economizing lumber and obtaining a greater velocity. Such flumes have been constructed mainly by lumber companies for transporting cordwood, railroad ties, planks, and boards from the mountains down to the lower lands, the water being used to some extent in irrigation. A better and more expensive type of flume is that having a semicircular section, such as shown in the accompanying view (Pl. XIX). These flumes are built of narrow planks or staves laid side by side, and held in place by iron bands run around under the flume and fastened by nuts and threads, by which the bands can be drawn up and the staves brought together, making a tight joint.

In crossing very deep depressions it is necessary to have a correspondingly high trestle, in order to carry the flume across on grade. Such high trestles are not only expensive, but are liable to destruction by storms, and in place of them have been built what are known as inverted siphons or wooden stave pipes. These pipes are built in a manner somewhat similar to the semicircular flume, being made of narrow plank carefully planed to a given dimension and held in place by circular iron bands or hoops. The ends of these hoops are

A PIPE UNDER 160-FOOT HEAD, SANTA ANA CANAL, CALIFORNIA.

B OLD FLUME AND REDWOOD PIPE REPLACING IT, REDLANDS CANAL, CALIFORNIA.

brought together by means of suitable screws, by which the hoops can be made smaller, drawing in the staves and compressing the joints. On the

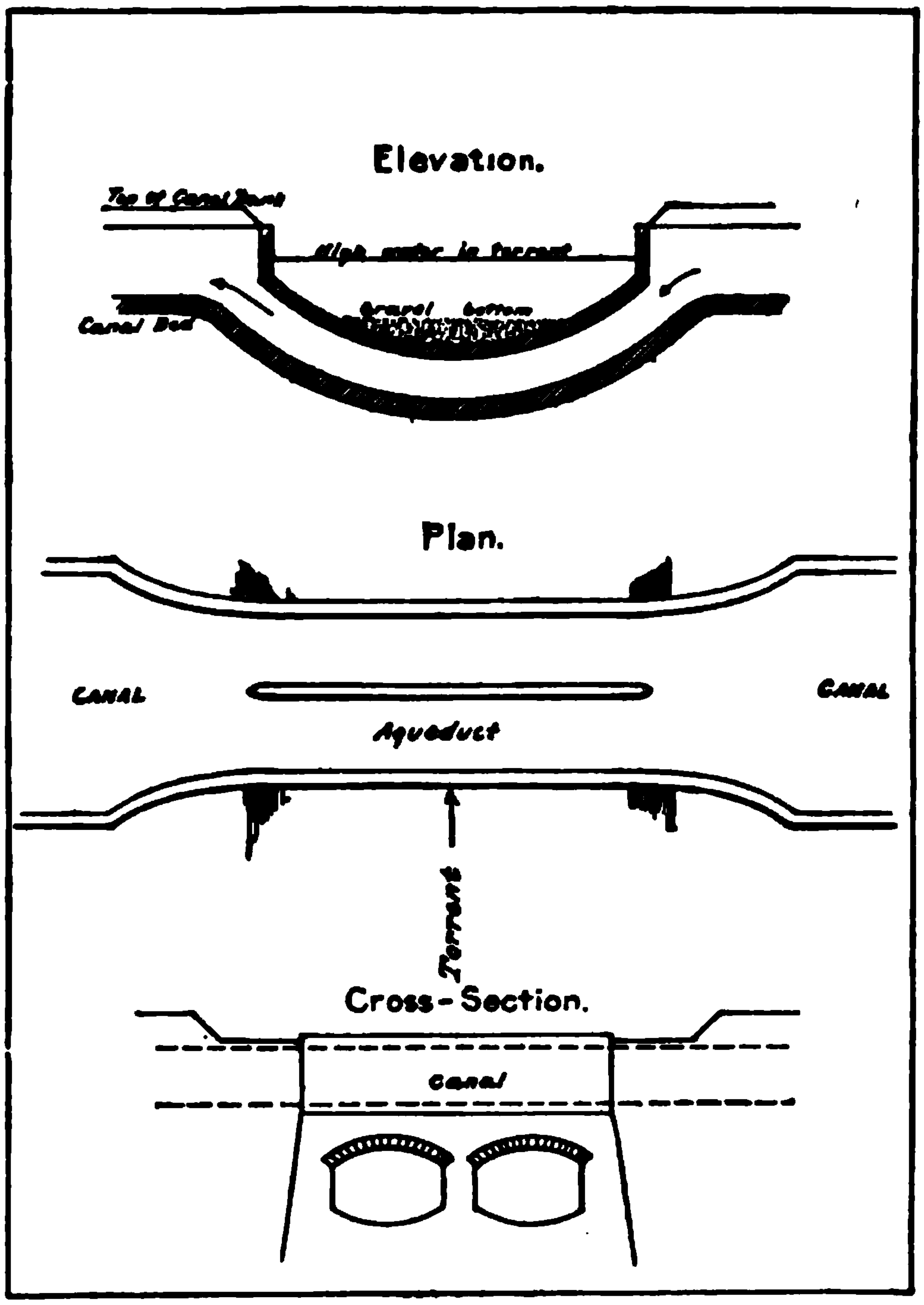


FIG. 37.—Siphon passage for canal.

accompanying illustration (Pl. XX, *A*) one of these wooden pipes is shown supported on a low trestle, the ends of the iron bands appearing as projections

regularly arranged around the pipe. On Pl. XX, *B*, is shown an old wooden flume of the ordinary type, and in the foreground a redwood stave pipe replacing it. A similar wooden pipe is shown on Pl. LIII, and an open semicircular flume on Pl. XXII, *A*.

Inverted siphons, whether of wood or masonry, are used to carry a canal under a side channel instead of over it. Figure 37 shows a masonry structure built beneath the bed of a torrential stream. In the upper part of the figure is a longitudinal section, the course of the water in the stream channel being shown by the arrows. In the middle of the figure is the plan showing a dividing wall for supporting the masonry roof of the inverted siphon. At the bottom of the figure is a cross-section of the central part of the structure, showing the siphon passing under the stream through the two channels formed by the dividing wall.

TUNNELS.

Where the ground is so irregular that it is impracticable to build flumes, recourse must be had to tunnels. These are usually short, cutting through rocky spurs. An excellent example of work of this character is that along Bear River in Utah, near the head of the canal taking water from the canyon below Cache Valley, shown on Pl. LV. The rocky walls are so steep that it has been found necessary to excavate a canal partly in the walls

A. TUNNEL ON TURLOCK CANAL, CALIFORNIA

B. TUNNEL IN EARTH ON CROCKER-HUFFMAN CANAL, CALIFORNIA.

and partly piercing projecting portions, making a substantial masonry structure.

Similar methods have been employed on the Turlock Canal in California, where a series of short tunnels alternate with open side-hill cutting as shown on Pl. XXI, *A*. Farther along the line of the canal it is sometimes necessary to make an underground passage to avoid a deep cut. Such a tunnel is illustrated at *B* on the same plate, this being on the Crocker-Huffman Canal, which takes water from Merced River, California. This skirts the base of the foothills on the south side of the river, and reaches the upland above the town of Merced.

These tunnels, when built through solid rock, do not require lining, but in many situations they must be supported by masonry or substantial brickwork, although in a few instances temporary wooden supports are preferred. In order to increase the velocity through the tunnel and thus reduce its area for a given volume of flow, a smooth concrete lining is usually provided for the bottom and sides.

LINING OF CANALS.

In portions of the United States where frosts do not occur to any considerable extent and where water has greatest value, experience has shown that it is desirable to line the ditches and canals with concrete or cement, thus reducing loss by percolation and making the channel so smooth that

the water moves rapidly even on slight grades. Often it is possible to trim the banks of the ditches to a uniform surface, and this is found to be sufficiently firm to serve as a foundation upon which to put a layer of cement mixed with sand and having a thickness of from $\frac{3}{4}$ of an inch to $1\frac{1}{2}$ inches. Where the bed and banks are not firm, it

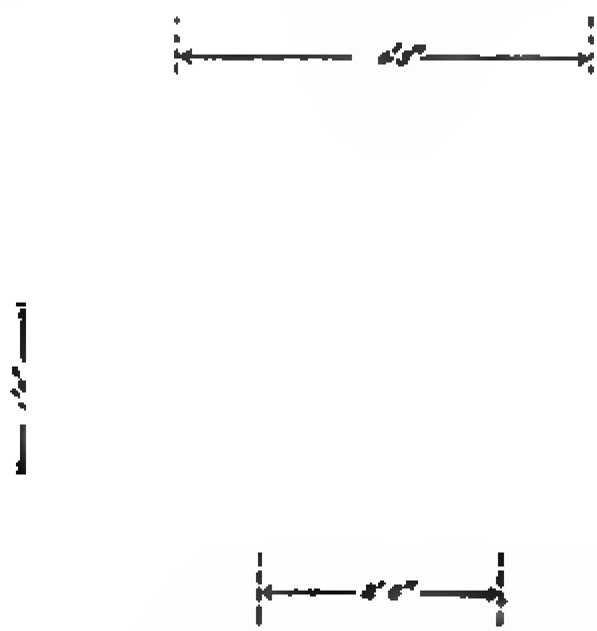


FIG. 38. — Section of cement-lined ditch with stop gate.

is necessary to pave or revet them with small stone, and then place upon this a coat of concrete made of small gravel and sand. The economy of water resulting from this careful construction has been found to be sufficiently large to justify a considerable outlay. The accompanying figure (38) shows a portion of a ditch lined with small stone covered with cement, and in this a stop gate for the purpose of regulating the flow. This gate is hung at the

points marked *a*, and can be swung up out of the way when not needed to check the water and raise it so that it will flow out into lateral distributing ditches or furrows.

The accompanying illustration (Pl. XXII, *B*) also gives a view of a portion of the Santa Ana Canal in Southern California as completed, with a lining of boulders roughly broken into shape and laid in cement mortar. The walls were first built against the sloping sides of the excavation, which was made in hard clay and natural cement gravel. These side slopes were generally 2 feet vertical to 1 horizontal. The bottom or invert was paved and the chinks were filled with coarse sand and spalls, with a layer of mortar roughly bedded on top. On this was laid the cement-plaster lining. The walls were laid with considerable care, giving a rough surface. They were from 16 to 20 inches thick on the bottom and from 8 to 10 inches thick on the top. In the view the width of the finished section is 12.5 feet on top and 7.5 feet deep at the centre.

EROSION AND SEDIMENTATION IN CANALS.

Since the greater part of the water used in irrigation must for economy be conducted by gravity, it is necessary to consider carefully the slopes to be given the conduits. This is especially true where a broad valley is to be irrigated from a stream whose upper course is only a few feet above the general level of the land. If the grade

is steep, it will either be necessary to lengthen the canal or to take water only to the lower land, leaving the higher portions of the valley dry. If, on the other hand, a very gentle grade is given, the water will flow slowly, and a very wide canal must be built to carry the necessary volume.

Equally important as the consideration of the relative height of the source of the water and the land to be irrigated, if not more so, are the effects of the slope of the canal upon the velocity of the water and the consequent cutting or filling of its channel. With steep grade the water moves with such rapidity as to pick up and carry along fine particles, and with increasing velocity larger and larger grains of sand or pebbles are moved, eroding the channel and carrying the loose material to points where it may be a source of annoyance or injury. The power of the stream to cut its bottom and sides increases very rapidly with higher velocities. Experiments indicate that by doubling the velocity of the stream its power to carry is not merely doubled but is increased sixty-four times; thus a very slight change in the rate at which water flows makes a very great difference in its behavior as regards carrying or depositing loose materials.

When, because of its great velocity, water has taken up and is carrying silt, sand, or gravel, and the velocity is reduced in any way, the heavier particles are immediately dropped. A torrential

A. SEMICIRCULAR FLUME IN SANTA ANA CANAL, CALIFORNIA.

B. CEMENT LINING OF SANTA ANA CANAL, CALIFORNIA.

stream, entering a pond or reservoir, deposits at once the boulders or gravel, then the sand, this being dropped a little farther on, and finally the clay or silt in the broader, stiller portions. A similar condition occurs in a ditch or a canal. Water from the river is sometimes muddy, especially in times of flood. On entering the canal, if the velocity is reduced at any point, some of this material will settle, forming a deposit along the sides or bottom. In this way the enlarged portions of the canal, such as a little embayment along its sides, will be gradually filled with sand or mud, the tendency being for a stream of uniform grade and volume to fill in the depressions or nooks along its course and to wear away projecting points or obstructions.

If, for a given volume of water, the cross-section of a portion of a canal is too large, the velocity will be checked and sediment deposited, reducing the size of the channel until this reduced area reacts by causing a slight increase in the velocity of the water. In other words, the flowing water tends to enlarge obstructions and to fill up and reduce the channels which are too capacious for its volume. Such a result is seen in the accompanying figure (39), where the broken lines show the original slope of the ground, and also the form of the canal. The flowing stream has gradually deposited mud and sand on each side, as shown by the dotted portions of the drawing, diminishing

the area of the cross-section to a point where the water is forced to maintain its velocity and continue to carry the sediment.

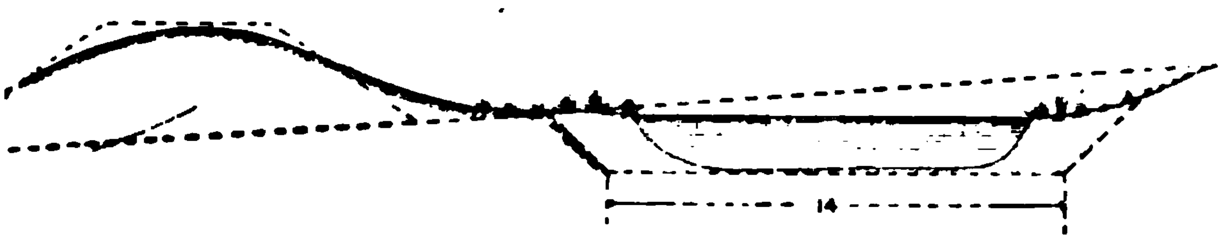


FIG. 39. — Cross-section of canal partly filled with sediment.

Some rivers, such as the Rio Grande, transport so large a volume of earth that the canals and ditches leading from the stream are quickly filled, and it is necessary to clean out the mud at short intervals. The view, Pl. XIII, *B*, shows one of these ditches with the mud piled high on each side, the result of the annual cleaning of the ditch. The cost of removing the sediment is often a large item in the operating expenses. For cleaning very large canals and for enlarging them, dredges have been used similar to that shown on Pl. XIV. These float along the canal as the material is dug out from the bottom and sides. By means of such a device a canal can be cleaned while in use, otherwise it is necessary to shut the water off and allow the bottom to become sufficiently dry for horses and men to work in it.

If, on the other hand, the grade of a canal is so steep as to erode the sides and bottom, some method must be taken to prevent this, for damage results in several ways. The erosion of the bot-

tom gradually reduces the level of the water in the ditch, and the material carried along is finally deposited at some place where it may choke the ditches or cover fertile land. The removal of fine material leaves the bed open and porous, the water escaping by percolation. The losses in this direction are prevented where the conditions are such that a small amount of silt is deposited and remains, filling or cementing the minute openings through which water would otherwise escape. The difficulties resulting from excessive grade of a canal are remedied by building what are known as "drops," two of these being shown on Pl. XXIII. They consist of suitable arrangements for the water to fall over low dams or weirs upon solid rock, or into a deep pool, where the force of the water will be expended without injury to the canal.

For very small ditches a great slope can be used, since the volume of water is not sufficient to move the large particles of sand and gravel; for example, on the farm lateral, carrying 1 or 2 second-feet, a fall of 50 feet or more to the mile may not be excessive, the velocity being retarded by the relatively great friction. On the other extreme, a large irrigation canal carrying 1000 second-feet may be in danger of injury if a grade of much over 6 inches to the mile is given it.

As a general rule it may be said that conduits of this character built in common earth should be

so proportioned as to have an average velocity of a little less than 3 feet per second, or 2 miles per hour, when carrying their full capacity. It is necessary, therefore, to take into consideration the amount of water to be carried, and from this deduce the size and shape of the cross-section of the canal or ditch, in order to obtain its velocity.

Many of the older irrigation works laid out by crude devices, such as a large triangle and plumb-line, have been given an excessive grade through fear on the part of the builders of getting too little fall. Some of these are as much as 50 feet to the mile, giving a velocity of the water of 5 feet per second, washing the bed of the channel and leaving only a mass of cobbles. The seepage through this material, even if the water is flowing rapidly, has been known in one instance to be over 20 per cent of the total flow in a course of four miles.

Where the grade of a ditch is so small that the water is flowing very gently, the conditions are sometimes favorable to the growth of aquatic weeds or grasses. Under the bright sunlight the water is warmed, and the development of these plants sometimes reaches such an extent as to completely fill the ditch. The water must then be turned out and the plants cut and thrown out upon the bank. Sometimes, where it is not possible to shut off the water, the weeds are raked out, or even mowed under water. In any case a

A DROP IN AN ARIZONA CANAL.

B CHECK WEIR AND DROP.

considerable amount of time and labor must be given to keeping these gently flowing streams free from obstruction. For this reason it is desirable to give ditches such a fall that they will keep themselves clean and yet will not erode their bottoms. This is a difficult matter to estimate, since the velocity of the water varies greatly at different stages, and the soils encountered by the ditch may range from gravels to the finest clays or silts.

In very muddy waters many of the aquatic plants do not develop, so that there is frequently an advantage in this respect, in addition to the value of turbid waters in fertilizing the fields. If the silt can be retained in suspension, not dropped in the ditch to fill it up, and be carried out to the fields of the farmer, the fine material left here on the surface may have considerable value in enriching the soil. The muddy waters frequently carry a considerable amount of organic matter and nitrogen in form available for plant use. It has been estimated, from chemical analysis, that the mud deposited on irrigated lands of Salt River Valley, Arizona, is equivalent in richness to fertilizers valued at $8 per acre. That is to say, if the irrigators of this valley were forced to purchase and apply to their farms commercial fertilizer of equal strength, it would cost $8 per acre. As compared with clear water obtained from artesian wells, the muddy water possesses certain advantages. On the other hand, it frequently carries with it noxious

seeds, and in extreme conditions may injure young vegetation by covering the leaves with slimy mud.

The greater part of the silt brought down by the rivers and carried out in the ditches occurs in times of flood, when there is ample supply of water, and when, by running the ditches full and at high velocity, the material can be carried through to the fields. Later in the year the waters usually become clear, unless the upper catchment basins have been denuded of their grasses and shubbery by overgrazing. In some localities the great bands of sheep, as shown on Pl. VI, *B*, have so completely eaten up the vegetation, and the ground has been so thoroughly pulverized by the small, sharp feet of the sheep, that every local rain brings down great quantities of soil, filling the ditches and keeping the water muddy.

The losses of water in canals through seepage and evaporation are frequently very great and have amounted to over one half the quantity received. The evaporation losses may be reduced slightly by increasing the velocity of the water, and thus shortening the time in transit. Seepage can be largely prevented, as above noted, by a cement lining, or by the deposition of the fine silt, which, when not in excess, is thus of great use and value.

CHAPTER V.

RESERVOIRS.

WHEREVER lakes, ponds, or large marshes occur on the head waters or along the course of a stream, fluctuations of the volume are to a large extent prevented. After a heavy rain the water, seeking the drainage lines, tends to flow off rapidly, but first fills the ponds; these overflow gradually, increasing the volume of the river, so that, instead of passing off as a violent flood of a few hours' duration, the storm results in the gradually increasing flow of a large volume of water in the river through days or even weeks.

The natural regulation of the flow can be further improved by placing obstructions at the outlets of these ponds, in order to hold the water when not needed in the river below. This has been done to a considerable extent for water-power development and for mining purposes. Natural lakes are, however, comparatively rare on the head waters of most streams useful in irrigation. Among the high mountains, especially under the peaks from which glaciers have issued, there are some ponds whose outlets can be closed

at small expense; but the water coming from these is almost insignificant in comparison with that which occurs lower down.

In the course of a river issuing from mountains, there are occasionally found broad valleys from which the water escapes through narrow canyons. These have resulted from the erosion of soft rocks, or more often from the disturbance of the drainage due to the uplifting of a part of the earth's crust, or by the outpouring of lava, or the formation of basaltic dykes.

It is apparent that, by closing the outlets of some of these valleys, the processes of nature can be imitated in regulating the flow of the streams. The flood waters can be held behind the artificial barrier, such as that shown on Pl. XXIV, and let out through gates whenever needed for power or for watering agricultural lands. At first sight it appears to be an easy matter to accomplish this, and throughout the arid region there are reported to be innumerable localities suitable for water storage. An examination of these, however, leads to many disappointments, as there must be a combination of several features to insure the practicability of reservoir construction.

REQUIREMENTS FOR WATER STORAGE.

The requirements for successful water storage on any considerable scale are: an abundance of water to be stored, capacity in which to hold this,

favorable situation for a dam, and suitable material for its construction, and also reasonable cost of labor, material, and land, if any is purchased for right of way or flooding.

The amount of water to be stored should in all cases be ascertained in advance by careful measurements made through a number of seasons at the point where the water is to be held. Disappointment and financial loss have resulted from assuming that there will undoubtedly be plenty of water, or by taking the statements of the "oldest inhabitants" to this effect. It is impossible to judge by the eye as to the volume of a flood. One which is particularly destructive and impressive in its apparent magnitude may, upon careful measurement, be found to have discharged an amount far less than anticipated. The intensity of the flood, or rapidity with which it moves, often gives an exaggerated idea of its volume.

Many serious blunders have been made because of lack of definite information concerning the water supply. Persons dwelling along the bank of a stream often entertain absurd notions concerning the quantity flowing at ordinary or high stages. They have no means of forming a correct conception of volume, and will confidently assert that there is enough water to irrigate a million acres, when, as a matter of fact, there may be sufficient for only ten thousand. The investor, and even the engineer visiting the locality, may become infected

with this optimistic spirit, and consider useless any further delay or expenditure to ascertain the fluctuations of the stream. Being impatient to begin work, they will take the statements of the people, and base their plans upon these.

In a well-known instance of the construction of a large storage dam which was under consideration for ten years or more, no measurements of volume of water were made, but when the constructing engineers were employed they were assured that the stream at that time was at a low stage. It was then carrying 2000 second-feet. As a matter of fact, it was really in moderate flood, and the low-water flow, six months earlier or later, was less than one-tenth of this quantity. The structure was planned and built without further delay, as the engineers did not consider that they had any duties beyond putting up the desired structure; but when finished, disappointment and loss of investment resulted, it being then found that there was not enough water.

The actual capacity of a proposed reservoir site is also often found to be disappointing upon careful survey. In going into the mountains where the slopes are steep, the eye is misled as to slight inclinations of surface. Valleys which seem to be flat are often found, when a levelling instrument is used, to be decidedly inclined, and instead of a dam 100 feet high backing up the water three miles, as at first estimated, it is not unusual to

discover that the water will be ponded for a distance of only one mile. In short, many localities which upon the first search are thought to be desirable are later found to have less capacity than anticipated. It is essential, therefore, to follow the preliminary examination by mapping each proposed reservoir site.

The accompanying drawing (Fig. 40) shows in reduced form a map of this character. The Land Office lines are shown by the rectangles, each of these indicating forty acres. Four of these make a quarter-section. The centre of each whole section is indicated by the symbols, Sec. 4, Sec. 5, etc. The dam site is in the lower right-hand corner of the draw-

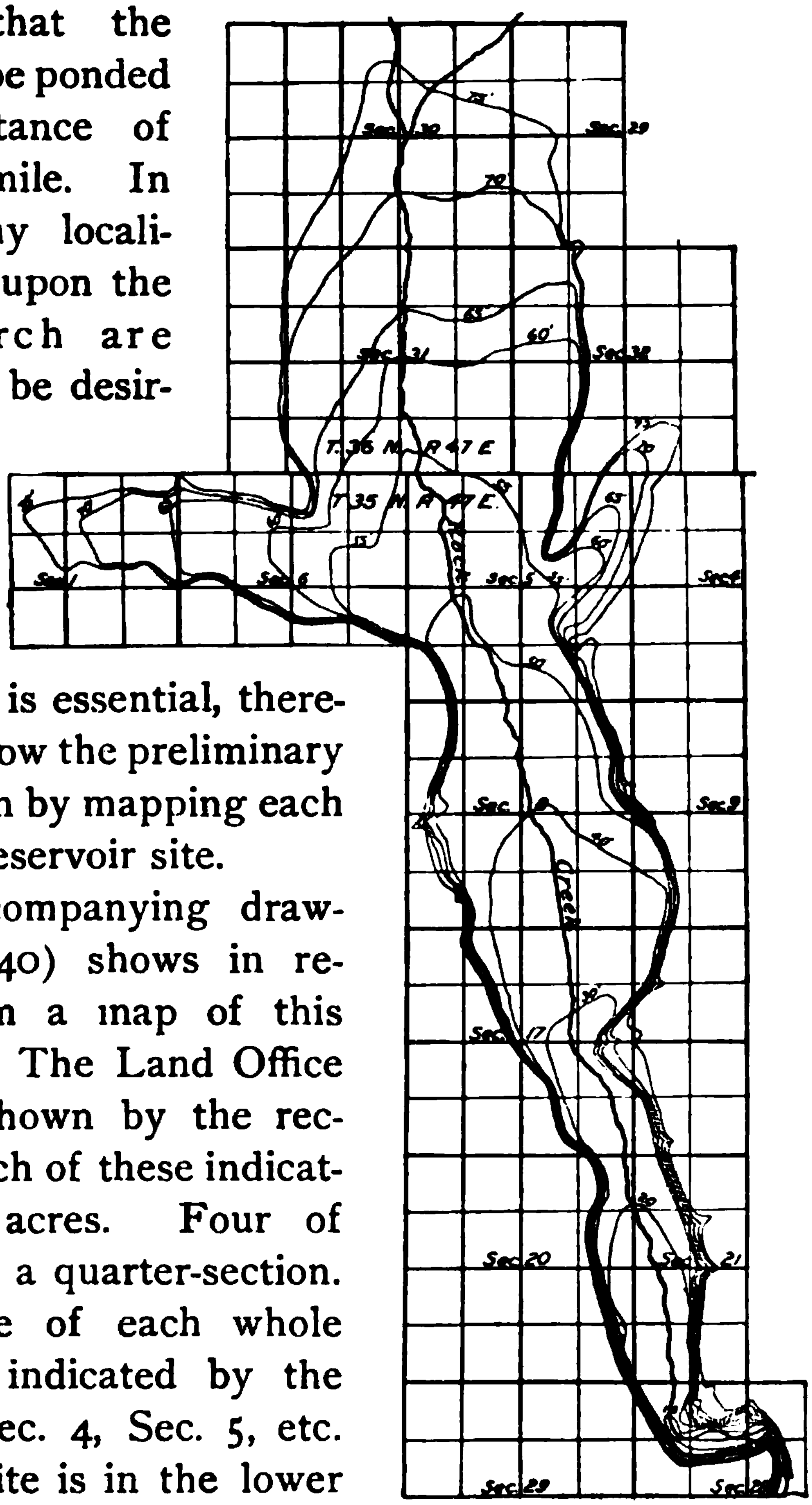


FIG. 40. — Map of a reservoir.

ing, where the contour lines come closely together, indicating a steep, narrow outlet. The first or lowest contour shows the location of all points 10 feet above the stream at the dam site. The next contour, marked 20 feet, gives points 20 feet above the bottom, or which form the shore when the reservoir is filled to a depth of 20 feet. The highest contour is 75 feet, and indicates the outline of the reservoir when filled to this depth. Where the contours run together the banks are steep, and where they are far apart the slope is gentle. From a map of this character it is possible to ascertain the area and capacity of the reservoir for all depths.

If there is plenty of water, and a place in which to hold it, the next question is the feasibility of building a dam. Every consideration demands that this structure should be made absolutely safe, and therefore the most substantial masonry is usually recommended. This must be founded upon bed rock and extended at each side into the solid walls of the canyon or gorge.

Where a river escapes from a valley through a narrow rocky cut, it might be and frequently is assumed that the water would keep this gorge washed clean and flow over bed rock, but this is rarely the case. At present, in the arid regions, the bottoms of nearly all the canyons are filled to a considerable depth with loose material. In the earlier ages the rivers, probably having more

SWEETWATER DAM, NEAR SAN DIEGO, CALIFORNIA

water, cut down into solid rock, and later, receiving a less supply, became overloaded with gravel and boulders during flood time, and have left these scattered all along the course, even in the narrowest places. This deposit of gravel and boulders, some of them weighing tons, usually has a thickness of from 20 to 100 feet or more. The foundation of a masonry dam must extend beneath all of this loose material, and the greater part of the expense is often incurred on that portion of the structure which is out of sight beneath the surface.

The clearing out of the débris in order to place the foundation upon bed rock offers many difficulties, since the stream must be passed over or around the work, and the latter kept sufficiently dry for the quarrying and stone-laying to proceed. With a depth of 50 feet or more, the cost of controlling the water, especially if floods occur, may become so great as to be prohibitory to the enterprise. The bed rock itself may be weak or partly disintegrated, and all of this loose or seamy material must be taken out to insure a perfectly watertight joint.

In carrying up the masonry structure from the bottom, a trench is cut into the side walls as far as open fissures or cracks extend, and care taken to make such a perfect joint between the dam and the rock that no leaks may occur. A small amount of water working its way under or around the dam will sooner or later wear out or dissolve a large

hole and weaken the structure, if it does not destroy it.

Besides these fundamental requirements there are others, such as cost of cement, which is largely governed by the distance it must be hauled from the main line of railroad, facilities for obtaining labor, and the value of the land or other property taken for the reservoir and dam site. All of these items must be carefully considered in connection with the value of the water when stored. This latter item is dependent upon the kind of crops to be raised and similar considerations. When all of these matters have been taken into account, out of a dozen reservoir sites considered, there is usually only one or two which can be recommended for construction.

KEEPING RESERVOIRS CLEAN.

There is still another item which must be recognized in some parts of the country, and this is the cost of removing silt from the reservoir. The floods bring down great quantities of material washed from the hills, rolling down boulders, gravel, sand, and clay, all of which may be caught in the reservoir. The boulders and gravel do not travel far at a time, and are usually soon deposited; but sand and especially fine clayey particles are often carried out into the reservoir, tending to fill it. Some of this material will remain in suspension and be drawn off, some can be washed out

through or over the dam, while the remainder must be removed by hydraulic dredges or similar devices. The necessity for cleaning out a storage reservoir has not yet been demonstrated by actual filling of any in the United States, but this is a contingency worthy of consideration.

The difficulties which may arise from the accumulation of sediment in a reservoir have been a source of needless alarm to persons who have given slight attention to the matter. The work of removing silt has been exaggerated by persons who, for one reason or another, wish to bring about delay in the beginning of construction of storage works by the government. There is no question that in some cases the accumulation of silt will become a source of annoyance and expense, but not an insuperable obstacle. The condition is somewhat analogous to that in railroad construction. It might be argued in advance that a railroad could not possibly be operated more than ten years, because at the end of that time all of the wooden ties upon which the rails are laid would be rotten and unsafe, and the rails must be all taken up and relaid, with great expense and delay. Experience, however, has shown that, although railroad ties do decay, they can be replaced without disturbing traffic. In the same way it can be shown that the silt accumulating in a reservoir can be removed from time to time.

Most of the reservoirs in which silt is liable to

accumulate are so situated that water is drawn from some point near the bottom, so that much of the silt, especially that near the dam, will be drawn out when water is taken for irrigation. The finer silt in the water in a large reservoir is kept in suspension almost indefinitely by wave motion and currents, the lighter particles floating for weeks, and even months. That portion of the sediment which has settled on the bottom is very easily disturbed; and when water is being drawn out of the reservoir, a stirring of the bottom by a dredge or other device will cause much of the material to rise and be carried off.

As the water in a reservoir is drawn down, exposing the mud banks, it is practicable to bring the incoming stream at the upper end around the top contour of the reservoir in suitably constructed ditches, and then turn the water down, washing out the mud banks either by the stream flowing across them or by confining the water in pipes and cutting out the accumulation of débris by hydraulic giants similar to those used in placer mining or in hydraulic construction, as shown on Pls. XXVIII and XXIX. An enormous amount of the light dirt can thus be moved at very small cost and run out through the lower gates of the reservoir.

Another way proposed for keeping reservoirs clean is by means of floating dredges, particularly those which pump up the mud by suction and

A. LAGRANGE DAM, NEARLY COMPLETED.

B. LAGRANGE DAM, WITH FLOOD PASSING OVER CREST AND SPILLWAYS.

deliver it into pipes conveying it to the shore. Such dredges can be operated by electric power generated by a small portion of the water drawn from the reservoir for use in irrigation. By such means, adapted to the local conditions, it is practicable to keep a reservoir clean just as other public works are kept in order. All great structures, whether for river and harbor improvement or for other purposes, require a certain amount of attention, and the fact that continual and intelligent care is needed for storage reservoirs cannot be used as an argument against their success.

MASONRY DAMS.

The oldest and most substantial structures for holding water are those built of masonry. The form of a dam of this character is shown in the accompanying figure (41), which is typical of a considerable number of works in the United States and in Europe. This is a section of the masonry dam in Tuolumne River, a short distance above La Grange, California. The dimensions are indicated, the thickness near the botton being 84 feet and the height nearly 120 feet. The stones composing the dam have been carefully set in cement, and those on the outer face have been cut to fit one another. A general view of this dam with the water pouring over it is shown on Pl. XXV. A plan is also given in Fig. 42, the direction of the water being indicated by the arrow.

On the right is the head of the Modesto Canal. The excess water entering the canal is allowed to escape over a long concrete spillway wall. Beyond this are waste gates, and then the regulator, which

FIG. 41.—Section of masonry dam at La Grange, California.

permits the desired quantity to enter the canal. On the left is indicated the position of the Turlock Canal, which comes out from a tunnel, the size of this regulating the amount which can enter the canal.

Structures of this kind, when well built, may be considered absolutely safe. There are, however, a number of precautions to be taken, which, if neg-

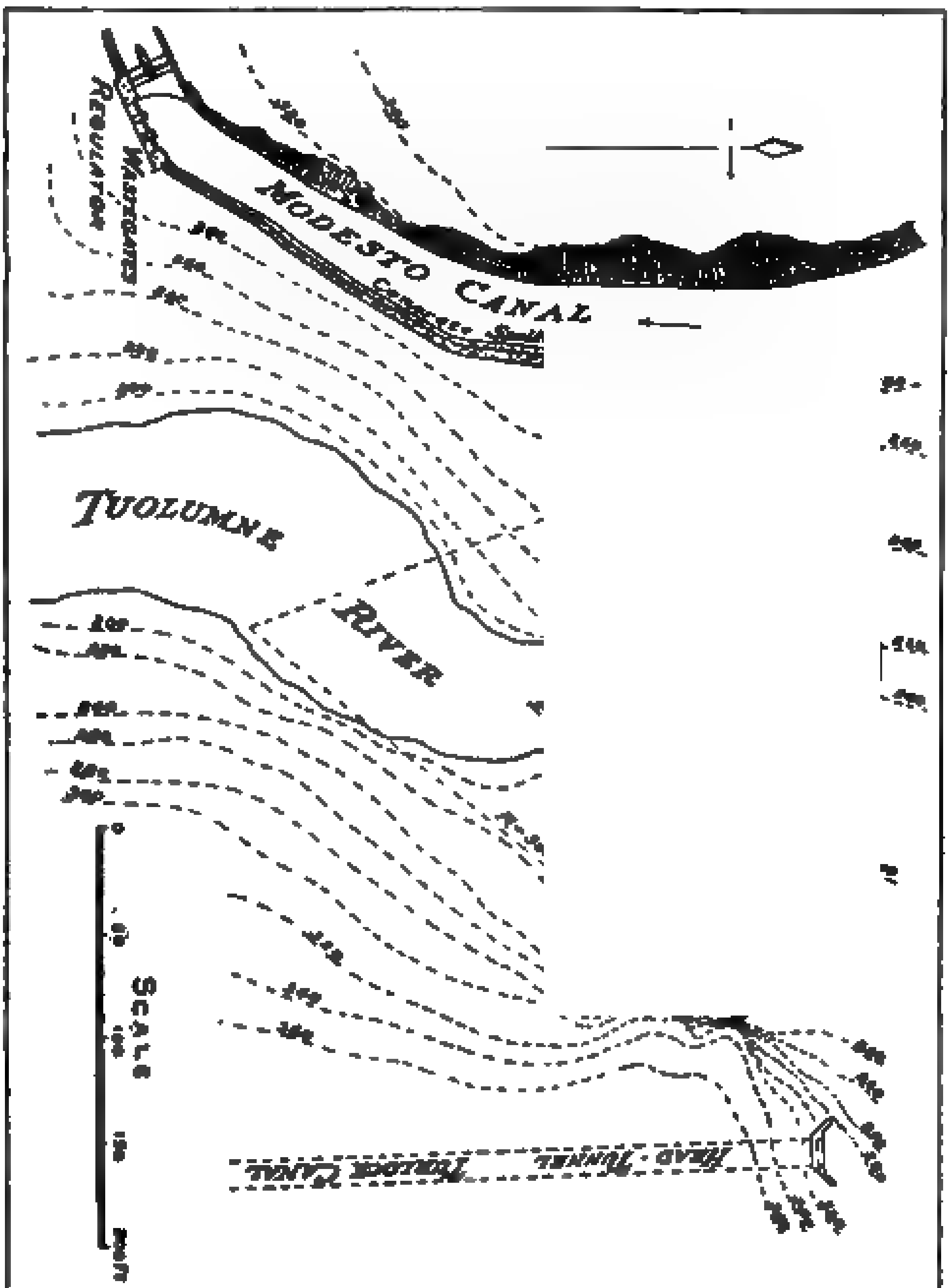


FIG. 42. — Plan of dam at La Grange, California.

lected, may be fatal, as shown by a few accidents which have occurred. The most notable of these in recent times is the failure of the Austin Dam in Texas, views of which are shown on Pl. XXVI. The upper picture is of the dam, looking across Colorado River toward the power house above the city of Austin. The lower view is from the opposite direction and shows the fragments of the dam immediately after its failure during the flood of April 7, 1900. At that time water to the depth of 11 feet was pouring over the top. Apparently a section of about 500 feet in length slid forward. This has been attributed to various causes, but the general explanation is, that beneath the dam was a layer of soft rock into which water penetrated during the flood, tending to float the dam, and weakened its strength to such an extent that it slid forward upon the yielding surface. This dam was located at a point of disturbance of the bedded limestone, and in the vicinity of what is known by geologists as a fault or zone of fracture, so that leaks or so-called springs appeared below the dam at one end, these being doubtless due to water finding its way into the shattered rocks and out at the first point of escape.

ROCK-FILLED DAMS.

Besides the masonry dams carefully laid by hand, a number of rock structures have been built in which the attempt has been made to lessen

A. DAM AT AUSTIN, TEXAS, LOOKING TOWARD POWER HOUSE.

B. PORTIONS OF AUSTIN DAM IMMEDIATELY AFTER FAILURE.

the expense by throwing in the stone, letting them take such position as they will, not filling the interstices with cement. These are known as rock-filled dams. The upper face must be made water-tight by an impervious wall of masonry, wood, or metal. The pile of rock behind this face serves to hold it in place and prevent it from being washed away. It is necessary to provide such structures with ample wasteways, so that the waters will not overflow the top and wash out the loose rock, weakening the structure. This has happened in the case of the Walnut Grove Dam in Arizona, where a sudden severe storm or cloudburst over-topped the structure, washed out the loose rock which held up the impervious face, and allowed the entire volume in the reservoir to burst out, overwhelming the settlements below.

When a person is standing on the side of a deep canyon, the thought occurs: Why not throw down a part of the walls of the canyon by means of enormous blasts, and allow the material to choke up the bottom of the gorge, and thus pond the water back and overflow the valley above? This experiment has been tried, and great quantities of rock have been thrown into a stream channel by titanic explosions of dynamite. The difficulty encountered, however, has been that the water quickly finds a way through this mass of loose material, and cannot be held for a sufficient length of time to repay the cost of outlay.

It is necessary to provide some form of impervious wall in the loose rock, or a tight cover at its upper face. To construct this after the material is in place is exceedingly difficult, since the accumulated rock tends to hold back the water and interfere with the construction of the retaining wall..

In southern California several dams have been successfully constructed by a modification of this method, these being at localities where the flowing water has not been sufficient in quantity to interfere with the work. Chief among these are the Morena Lower Otay dams, easterly from the city of San Diego. After the heavy explosions, the ground immediately above the rock heap was cleaned away to bed rock and a concrete base prepared for the insertion of a steel plate. This plate was continued upward across the narrow canyon, being protected on each side by a thin layer of asphaltum and a thickness of concrete against this. On both sides of the plate was placed the loose rock (Pl. XXVII, *A*), this being lifted and deposited in position by means of derricks and overhead cables. The completed structure consists of a substantial pile of rock, the impervious steel plate preventing leakage.

As indicated by the preceding statements, the most desirable structures for holding water are those built of substantial masonry. It occasionally happens, however, that dams of this kind cannot be built for lack of suitable material conveniently

located, and other forms of structure must be considered. For this purpose earth, timber, iron, and steel are sometimes employed. Steel has been used through the interior of a dam, as just noted, and also for the entire structure, strength being given, not by the weight of rock, but by a system of bracing similar to that employed in ships and great buildings. There is no difficulty as to the original strength, but doubt has arisen in the minds of many engineers as to the permanence of the work, because of the possible effects of rust or other forms of deterioration.

Timber dams are widely used, especially for lumbering operations and for mill purposes. These have been built in great numbers upon rivers flowing from forested regions, where timber is plentiful. They are usually of relatively low height, and consist of logs framed to form cribs, these being filled with large stones and thus held in place. The upper face of these dams is covered with a sheathing of planks, making the dams nearly water-tight.

Timber or log structures of this kind are used to a small extent in the arid region, but they are temporary expedients, resorted to with the idea of replacing them by better works as soon as the irrigators acquire the means with which to make a more substantial dam. As used for this purpose, they are for the most part at the outlets of small natural lakes, partly closing these and raising the water at the time of the spring floods. These

timber dams are designed to accomplish the desired end temporarily at the least possible cost. A view of one of these temporary dams is given on Pl. XXVII, *B*.

EARTH DAMS.

Earth is largely used for holding water in localities such as those upon the edge of the Great Plains, where there are broad basins or shallow depressions into which water can be taken from local floods. It is usually necessary to provide a very long and relatively low bank to increase the storage capacity of these basins, as in this situation there is rarely any rock or timber. Earth must, therefore, be used, carefully compacted and piled up in such quantities that the water cannot seep through.

Percolation through an earth bank is prevented by carefully preparing the foundations, to secure a perfect union between the underlying earth and the material placed upon it. All loose soil and vegetal matter must be removed from the foundation of the earth bank, and along the centre a deep trench dug. This trench is then filled with clay, carefully worked into place. This is designed to cut off the water which otherwise might seep beneath the foundations. The clay or puddled wall is continued upward through the centre of the dam, forming an impervious sheet, which prevents any leaks from extending through to the lower side. The preparation of this puddled wall requires great-

A. LOWER OTAY DAM, CALIFORNIA, SHOWING METHOD OF PROTECTING STEEL PLATES.

B. CONSTRUCTION OF TIMBER DAM AT BLUE LAKES, CALIFORNIA.

est care and attention, as upon it depends largely the safety of the structure. A leak once started through an earth dam may enlarge rapidly, the flowing water eating away the loose material with increasing rapidity.

Ample provision must be made to prevent the possibility of the water overtopping the bank at any point, as this is easily eroded and would be washed away in a few hours. To do this, a broad wasteway is usually cut across a portion of the natural rim of the basin, this being several feet lower than the top of the artificial bank. By providing a broad place of escape across hard, undisturbed material, a sudden flood can be released before it overtops the embankment.

Outlets for such reservoirs are sometimes provided at the lowest point in the dam, especial care being taken to make this point of weakness as strong as possible. It has been found preferable in some instances to tunnel through some other part of the basin rather than to run the risk of leakage around or along an outlet built in the artificial bank itself.

Earth reservoirs of large capacity have been built in this way, and also innumerable small ponds or tanks for stock water or for irrigating gardens and orchards. These tanks are made from 100 to 500 feet in width, and are frequently filled with water by means of one or more windmills, as described on page 268. They are frequently made

on the surface of the ground by scraping the earth from the outside, depositing this carefully in layers, and wetting and rolling, or trampling, it firmly into place. The banks thus built have a slope on

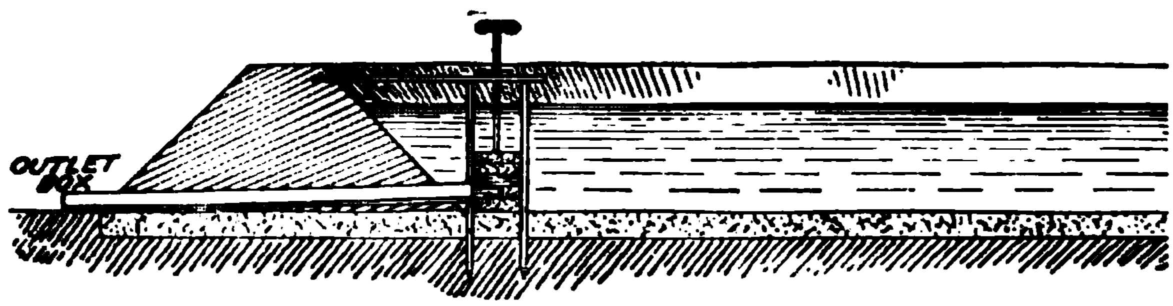


FIG. 43. — Portion of earth reservoir showing outlet.

each side of at least $1\frac{1}{2}$ or 2 feet horizontal to 1 vertical. The layers of dirt are so placed as to be lower in the centre of the wall, the finer material being, if possible, kept here as each layer is put into place or still better, a puddled wall of clay is put through the centre of the dirt bank.

These tanks may be either circular or rectangular in outline. An outlet is usually provided at the lowest point by inserting a substantial masonry or tile drain with gate, or a stout wooden box, care being taken to compact the earth around the outlet.

Frequently when a small reservoir of this kind has been completed, it leaks so rapidly that the water disappears before it can be used. It is then necessary to puddle the bottom with fine earth or clay, sometimes straw and stable manure being used. Cattle, horses, sheep, or goats are turned into the reservoir, and are fed there or kept moving

around, trampling the muddy bottom until it has been completely worked over. In this way it is soon rendered water-tight, especially if fine silt or muddy water is kept in the reservoir for some time.

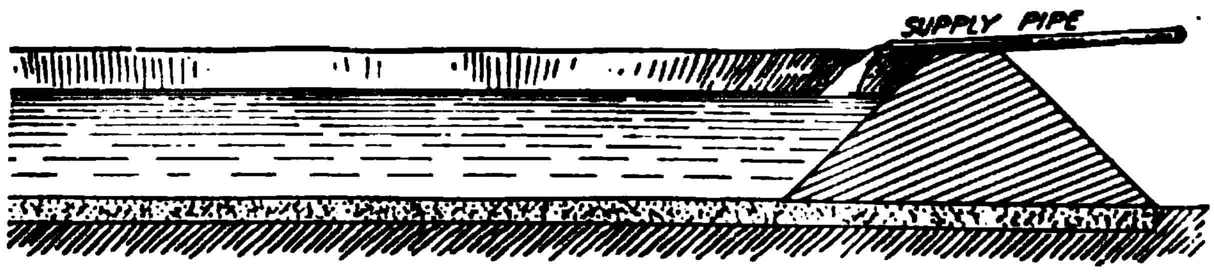


FIG. 44. — Portion of earth reservoir showing inlet.

The illustrations, Figs. 45, 49, and 50, show easily constructed devices for an outlet and gate for one of these small reservoirs. It is usual to construct this outlet of boards or plank, in the form of a long box from 8 to 18 inches in width and height. For permanence it is preferable to use a

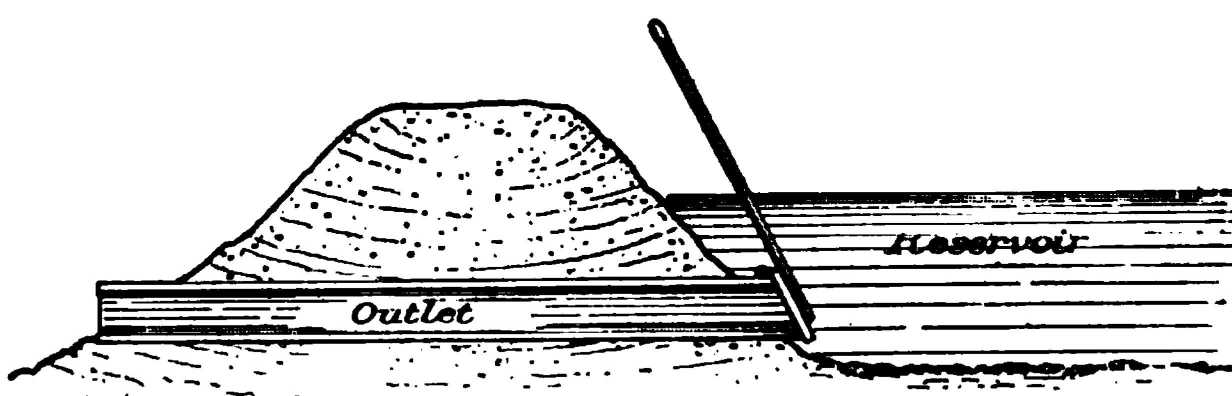


FIG. 45. — Section of reservoir bank showing outlet.

pipe of metal or cement, but the cheaper wooden outlet will suffice for a number of years. Around this outlet the clay and fine earth is very carefully packed to prevent leaks. On the upper end of the outlet is placed some form of gate or a simple

hinged cover, as shown in Fig. 45, with a handle reaching above the water to a point convenient of access.

The top of these reservoir banks is usually made at least 2 feet in width. If, therefore, the bank is to be 5 feet high, the slopes on each side should extend out at least 7½ feet, making the width of the bank at the bottom 17 feet. Earth for building the wall should not, as a rule, be taken from inside the reservoir, as this disturbs the natural surface and tends to increase the leaks.

The banks of reservoirs made of earth must be protected from washing by the waves, by being covered either with sod in the case of small tanks or ponds on a farm, as shown in Pl. XLIII, or with a heavy, well-laid revetment of stone for larger works. An efficient form of protection is made by roughly weaving willow twigs into a mat held in place by stone or earth. In course of time the willows take root and hold the bank from erosion.

HYDRAULIC DAMS.

An ingenious method of constructing earth dams for reservoirs has been practised in the West, the method being suggested by the operations of the miners for placer gold. Small particles of this precious metal have been found scattered through gravels which formerly were a portion of ancient stream channels. To obtain these small flakes or larger nuggets the gravel is washed, the heavy

A. BUILDING DAM BY HYDRAULIC PROCESS AT SANTA FÉ, NEW MEXICO, SHOWING HYDRAULIC GIANT IN USE

B. BUILDING DAM BY HYDRAULIC PROCESS AT SANTA FÉ, NEW MEXICO, SHOWING OUTLET PIPE.

particles settling, and the gold being caught in blankets or seized upon by mercury suitably held in tiny pockets beneath the moving stream of water carrying the sand and gravel. To bring the gravel to the point where the gold can be obtained it has been customary to arrange devices by which a column of water under heavy pressure can be directed against the bank or deposit where the gold is supposed to exist. By means of ditches, flumes, or other conduits, water is brought from some mountain stream and led out to a point where it can be conducted by a pipe downhill, finally terminating in a nozzle, forming part of what is known as a "giant." The stream directed by the giant strikes with tremendous force, as shown on Pls. XXVIII, *A*, and XXIX, cutting its way into hills of sand, clay, and small boulders, tearing these out and throwing them aside, the waste water washing them away and assorting the material according to its size and weight.

In placer mining the débris thus resulting was formerly allowed to accumulate in the stream channels, and, being washed down by floods, was piled up in the lower valleys, filling the beds of the streams, interfering with navigation, and causing the rivers to overflow their banks, carrying mud, sand, and often stones far out over fertile land and ruining thousands of farms. Because of the destruction thus wrought, this form of mining has been prohibited by law, except in localities

where the débris can be impounded and kept away from the rivers.

The amount of material transported in this way is very great, and it occurred to engineers that this method might be put to other purposes. Accordingly, instead of turning the débris loose to follow the stream channels, it has been carefully conducted to the designated spot, and the accumulation there so arranged that a symmetrical pile will be formed of any desired shape. For example, if an earth dam is to be built, the material rolled along by the water is carried in suitable flumes to the selected spot. On leaving the flume the small boulders and coarse gravel are at once deposited; the sand flows on farther, and the fine mud is carried in suspension for considerable distances. It is thus possible to deposit the coarse gravel on the outer slope of the dam, and, by raising the sides, cause the finer material to be laid down in the centre of the dam, thus making a uniform gradation in coarseness from a central impervious wall of clay out to the heavy coating of gravel on the upper and lower side of the dam. The symmetrical form can be easily preserved by shifting the point of outlet, and thus a structure is made of the exact shape called for by the plans. The material, being deposited under water, is thoroughly compacted, and there is less danger of settlement or of porous layers being formed than in the case of dirt placed by carts or scrapers.

EXCAVATING DEEP CUT FOR CANAL BY HYDRAULIC PROCESS.

The speed and small cost at which material can thus be moved are extraordinary, the actual expense being stated to be from four to eight cents or more per cubic yard, according to conditions or the ease of obtaining the necessary proportion of clay, sand, and gravel. A number of dams have been constructed in this way, the most notable being in California and in Texas. In a few instances, particularly on the Canadian Pacific and Northern Pacific railway, large cuts have been made through hills of gravel and clay, the material being washed out and deposited to form embankments.

Plate XXVIII, *A*, illustrates the process of breaking up the soil above and near a dam which was begun near Santa Fé, New Mexico. The stream from the hydraulic giant, after tearing out the gravel, sand, and clay, washes these into pipes, the lower of which is shown on the same plate at *B*. Here the material is deposited to form the dam. On the next illustration (Pl. XXIX) are shown two streams making a cut through a ridge, this being on the line of the Turlock Canal in California. The cost of the excavation was 31 cents per cubic yard, and this was reduced by the value of the gold found, amounting to 4 cents per yard.

STORED WATERS.

The control of water which has been held in reservoirs is, by custom and law, governed by regulations different from those governing water taken

directly from a flowing stream. It is considered that the water thus held for a specific tract belongs to the person or association owning the reservoir, and is subject to the control of the owners. It is not, strictly speaking, property, but the persons owning the reservoir become owners of the water only when it is segregated from the waters belonging to the public and held for use on land, to which the right to the use of the water attaches. Its complete utilization is, moreover, to a large extent dependent upon the situation of the reservoir with respect to the lands to be irrigated.

Most reservoirs can be considered as belonging to one or the other of two classes: those situated near the head of the stream, and those lower down upon the plains. The head-water reservoirs receive their supply directly from melting snow or rain, being for the most part located upon the upper tributaries. Water from them must be taken back into the natural channel, and, mingling with the stream, flow downward for many miles, passing the heads of various ditches, until it reaches the canal for which it is destined.

The other class of reservoirs are those among the foothills or out on the plains where depressions have been found suitable for holding water in the vicinity of the irrigable farms. The supply is taken to these by means of large feeder canals heading on the river and receiving the flood flow or the surplus at times when not needed for direct

irrigation. From these low-lying reservoirs water is conducted to the fields without mingling with other water in a natural channel.

It is apparent that the control of these two classes of works offers a wide difference in theory and in practice. In the case of the high-level reservoirs, the problem after the water is stored is to get it safely to the land. With the low-level reservoirs, on the contrary, the chief difficulty is to bring water into the reservoir. After it is there, it may be considered as removed from interference.

As a rule, reservoirs are not built until after the natural flow of a stream has been entirely appropriated and more land brought under irrigation than can be supplied. Then comes a time when water must be had and steps are taken to supply the deficiency. If suitable sites are found on the head waters, dams are built and water is held for the benefit of the lands under a particular ditch, or belonging to an association of farmers. When the dry season of the year occurs, a quantity of water is allowed to flow from the reservoir into the natural channel. If this channel were a closed pipe with all outlets guarded, the same amount of water could be taken out below that is turned in above; but, owing to evaporation and other causes, there may be considerable losses along the stream, and allowance must be made for these.

A further complication is that at this time of year most of the ditches along the stream are

short of water. Some of them claim the entire flow of the stream at the point of diversion, and leave their head gates open to catch occasional floods. There is no way to distinguish the water which comes from the reservoir from that of a local rainstorm, and by accident, if not by design, much of this may be taken at one point or another. Even if a ditch has claim only to a certain volume of flow or a certain portion of the stream, there is always opportunity for dispute as to the quantitative relation which the stored water bears to the natural flow.

A condition frequently arises under which the ditches heading highest on the river obtain by chance more than their share of the natural flow during the time when the water is coming from the reservoir. The owners below endeavor to take out the amount to which they are entitled, and controversy at once arises whether the water at any given point is stored water or the natural flow. Unless every head gate is watched, there is a tendency for the water from the reservoir to disappear at one point or another. If belonging to a ditch low on the river, very little of it comes down. If, on the other hand, the owners succeed in obtaining as high as 80 or 90 per cent of the quantity turned out of the reservoir, their success is usually due to the most strenuous exertions, and is accompanied by the belief on the part of other ditch owners that they have somehow been robbed of what is due them.

SKYLINE CANAL, DIVERTING WATER ACROSS THE MOUNTAINS.

Because of the controversies involved, and the practical difficulties of distributing waters stored in the upper part of the catchment basin of a river system, it is believed by many that such storage should be permitted only for the benefit of all irrigators, and not for any particular owner or group of farmers. Natural reservoir sites should be dedicated to public use and the water held in them employed in maintaining the flow of the stream during the low season, being taken out in accordance with local customs or equities. Only in this way can the largest benefits result from works of this character.

The supply for low-lying reservoirs is taken from the natural streams by canals, which in one sense compete with others along the river. These canals may be employed during the irrigating season to take water directly to the fields, and when other ditches are closed they receive the waste water and take it to the reservoirs, where it is held over until times of need. In early spring, also, they often carry water both to the reservoir and to the fields when there is ample for both purposes. Priorities to use of water for irrigation and for storage are the cause of frequent disputes, due to the gradually increasing demand for water for direct irrigation, and the resulting encroachments upon the quantities which previously have been available for storage.

The available water supply along a stream may,

in some localities, be increased not only by storage, but also by bringing, around or through a divide, the head-water streams which flow in other directions. For example, on the east side of the Rocky Mountains, in Colorado, all of the water is needed for irrigation. On the west side the streams are more than sufficient to supply the land in the narrow valleys. In a number of cases ditches have been taken from some stream flowing westerly, and these have been carried around or by tunnels through rocky spurs, dropping water finally on the east side of the range and thus increasing the flow. Occasionally this has been done to the detriment of irrigators lower down the stream thus diverted, but, as a rule, works of this character have been highly beneficial. One of these ditches winding around the mountain summits is shown on the accompanying plate (XXX). This is known as the Sky Line ditch, built at an altitude of 10,000 feet, which takes water from one of the upper tributaries of the Laramie River and diverts it to Cache la Poudre Valley, Colorado.

CHAPTER VI.

METHODS OF IRRIGATION.

THE devices and structures described on preceding pages are for the purpose of bringing water to the highest point of the field of the farmer, so that he will be able to conduct this by easy channels to the plants requiring moisture. The methods of doing this are diverse, depending upon the climate, soil, and crop, and especially upon the skill and experience of the irrigator. In this respect there has been little scientific information available. While methods of conserving and conducting water have been improved under the stimulus of modern invention, the application of water to the soil has been left to experience gained largely by accident and through failure. There is great need of long-continued systematic study and acquisition of knowledge concerning the actual effect which the water has upon the soil and upon the plants. We can see the ultimate result, but have only a vague conception of the steps by which this result is produced.

Most of the farmers practising irrigation in the United States use quantities of water far in excess

of those theoretically demanded or actually beneficial to the crops. This is in line with the general prodigality of pioneer life, and with the habits of shiftlessness so easily acquired where an abundant supply of water can be had. It is so much easier to open the ditches and let the water flow freely than it is to guard and guide each tiny rill, that for economy of time and labor, if not from actual indolence, the irrigator is apt to let the water go its own way.

It is sometimes stated that irrigation is a lazy man's way of cultivation. The reverse is the case wherever the best results are obtained. Irrigation, properly conducted, means intensive farming and application of water with great care, followed by thorough cultivation of the moistened soil.

Different plants require different amounts of water. Some are satisfied with a very little. Others require a great deal, and cannot do without it. Still others are relatively indifferent as to whether much or little water is applied; they have the habit of adjusting themselves to circumstances. Each crop therefore has different needs, and the practice of irrigation must vary accordingly.

It is not merely the character of the plant which has to be considered, but also the quality of the soil. Certain soils receive and transmit water with great rapidity, — such, for example, as sand and gravel. Others, like clay, take water slowly and hold it with great tenacity. Thus the manner and time

of irrigating certain plants will vary according to the ability of the soil to hold and supply water as needed. If the moisture escapes rapidly, as from sand, the plant after a few days is not able to receive enough and begins to droop. On the other hand, if the soil is very compact and the water is held from escaping, the soil may become waterlogged, air cannot penetrate the interstices, and the plant suffers from drowning.

There is still another factor in the production of crops which must be considered besides sunshine, soil, and water. This is the low order of vegetal life known as nitrifying organisms. These, in the presence of air and moisture, manufacture food for the plant and are its servants in preparing material upon which it thrives. A certain amount of water is needed for these nitrifying organisms, but, on the other hand, too much water stagnates and destroys them. Thus it is that there is a very delicate adjustment to be preserved in respect to the amount of moisture in order to produce the best results. These conditions the successful irrigator learns by experiment and failure, and unconsciously follows certain rules which he is usually unable to put into words.

There has been very little progress in the practice of irrigation from the methods of ancient times. This is due largely to the fact that the men who are now bringing new lands under ditch have for the most part received their training as

farmers in humid regions, and find it difficult to unlearn many of the facts which they regard as fundamental, and to reverse the habits of half a lifetime. They hesitate to adopt the methods of the Indians and Mexicans, despising these as crude or childish. Nevertheless, these primitive peoples have, through the experience of generations, acquired certain ways which are worthy of study, particularly in the direction of using the smallest possible amount of water in oases on the desert. When they have plenty of water, the Mexicans use it wastefully; but where the amount is extremely limited, some of them, particularly the agricultural Indians of the Southwest, have acquired the art of utilizing every drop. Even the drippings from the family water jar are arranged to fall upon a growing plant,.and the moist spots are carefully guarded for the growing of corn or beans.

The water having been brought to the field, the farmer must first, in order to apply it successfully, build small laterals or distributing ditches to direct it toward the portions of his land where the plants are being cultivated. For this purpose he ploughs out a ditch or turns up two small parallel banks of dirt, keeping the bottom of the ditch as near the level of the ground as possible, in order that water may flow out when the banks are cut. A section of a small field ditch is shown in the accompanying figure (46), the sides being formed by

earth taken largely from outside the ditch in order not to lower its bottom.

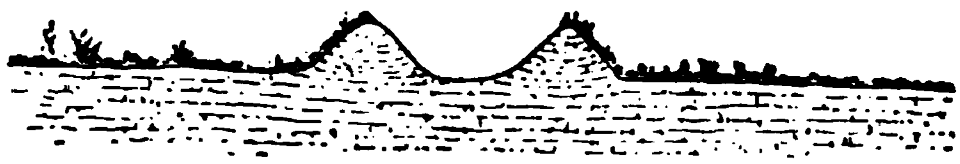


FIG. 46.—Section of small distributing ditch.

It is frequently necessary to carry one of these small laterals directly across a low portion of the field, and for this purpose earth is banked up and the two sides are raised slightly, making an elevated ditch, as shown in Fig. 47. These are usually constructed with plough and scraper, the earth being carefully packed by trampling, in order to prevent settling when the water is turned in.

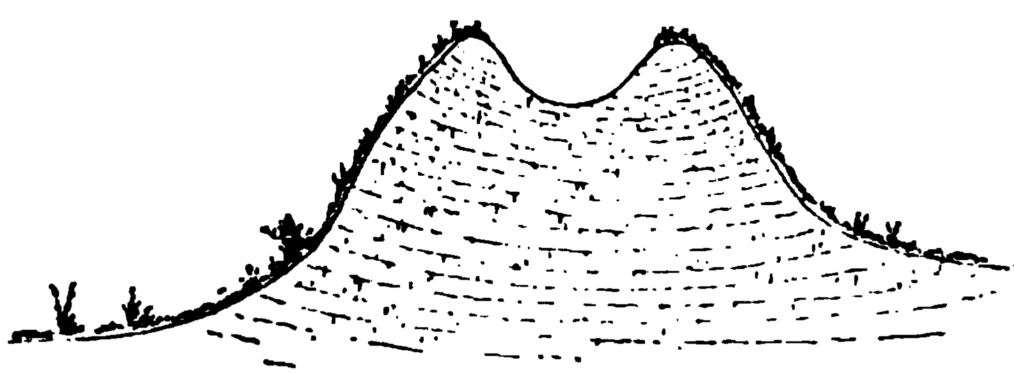


FIG. 47.—Section of small raised ditch.

Occasionally the depression to be crossed is quite deep, or is a ravine receiving storm waters, which by the construction of the raised ditch would be dammed back, and, accumulating, might wash away the obstruction. To reduce the cost, or to permit the passage of storm waters, small flumes are built similar to those used on the main

ditches and canals. The accompanying figure (48) gives sections and elevation of some of the flumes

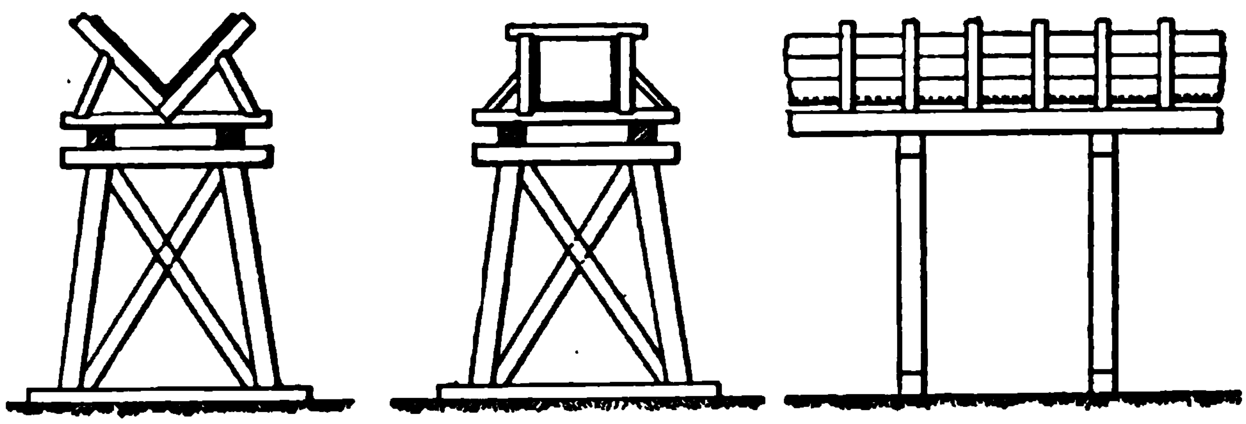


FIG. 48. — Sections and elevation of small flumes.

used on farm laterals. The section on the left shows a V-shaped flume, built for economy of lumber; the rectangular form is, however, more generally employed.

Water is taken from the main ditch into these farm laterals, and from one lateral into another, by

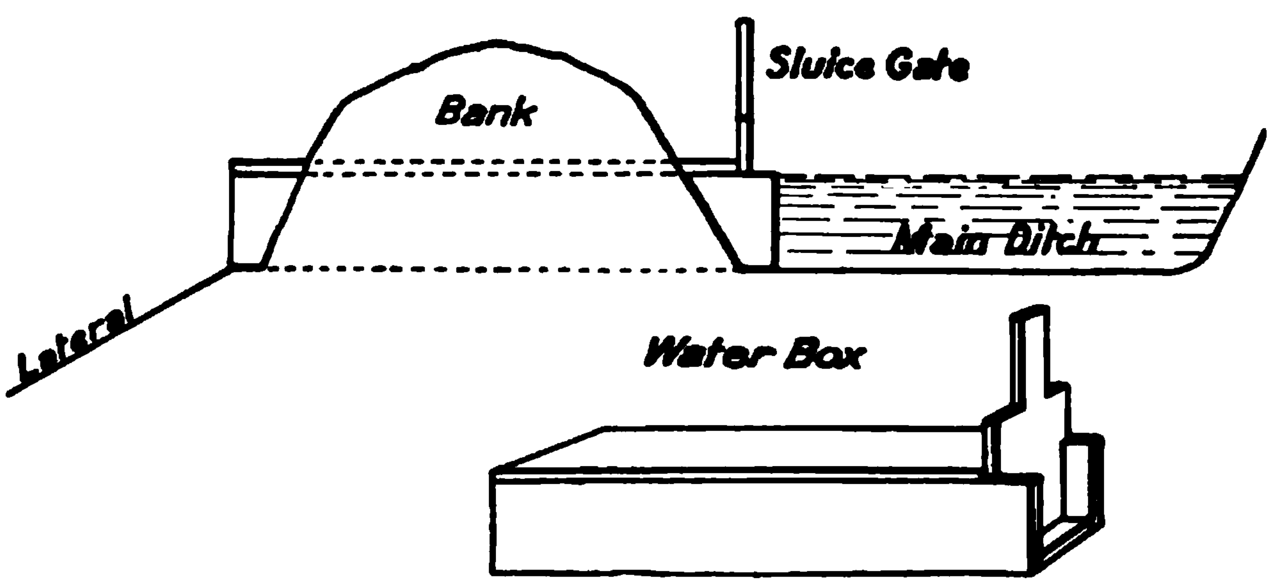


FIG. 49. — Box for taking water from main ditch.

means of small gates or boxes. The crude method is sometimes employed of simply cutting the bank of a ditch by means of a shovel, and

when sufficient water has been taken the hole is filled again. Unless this is carefully done, however, there is liability of leaks, and the water may wash out a large hole before it can be checked. A simple form of gate or box is shown in Fig. 49. This is built of boards or plank, and has a small sliding gate or shutter at the upper end. These boxes should be bedded in clay carefully packed to prevent leakage.

The details of the construction of a gate for one of these lateral ditches or for a small earth reservoir are shown in Fig. 50, which gives the dimensions of the material used. The sliding faces, where the gate is brought in contact with its bearings, must be made smooth in order to be as nearly water-tight as possible. Frequently leather or rubber facing is used, in order to insure a more perfect fit. In these illustrations only the more simple devices are shown, those which are usually constructed by the irrigator. More complicated or machine-made gates and boxes may be purchased from manufacturers, but these are only employed after irrigation has developed beyond its early stages. It is the home-made, somewhat crude, devices which are used in conquering the desert.

FLOODING IN CHECKS.

The simplest way to apply water to the soil is that imitated from the operations of nature when

a river overflows its banks. Water is spread over the surface, and after this has drained away, plant life starts into luxuriant growth. In a similar

FIG. 50.— Details of construction of box for distributing water.

manner, the irrigator may turn the water from a ditch over a level field and completely submerge it. Perfectly level fields are, however, comparatively rare, and the next step is to build a low

ridge around two or three sides of a slightly sloping field, so that water, when turned into it, is ponded. These low banks are commonly known as levees or checks. In construction they are generally laid out at right angles, dividing the land into a number of compartments, as shown on Pl. XXXI, *A*, each usually lying at an elevation which differs slightly from that of the others. Water is turned from the ditch into the highest

FIG. 51.—Portion of field divided by rectangular levees.

of these compartments, and when the ground is flooded the bank of the lower side is cut and the water passes into the next field, and so on until each in turn is watered.

This flooding in rectangular checks is practised most largely by the Mexicans living along the Rio Grande in New Mexico and in adjacent portions of the Southwest. These farmers follow the example of their ancestors and subdivide the land into little rectangles, often not more than a rod or two

long on each side. The banks are thrown up with spade or shovel, and the ground between the banks is tilled with a heavy spade or mattock. The grain when ripe is reaped by hand, and, in short, in all of their operations the greatest imaginable labor is expended. Water, when had in abundance, is turned into these checks, and the quantities used are often extremely large.

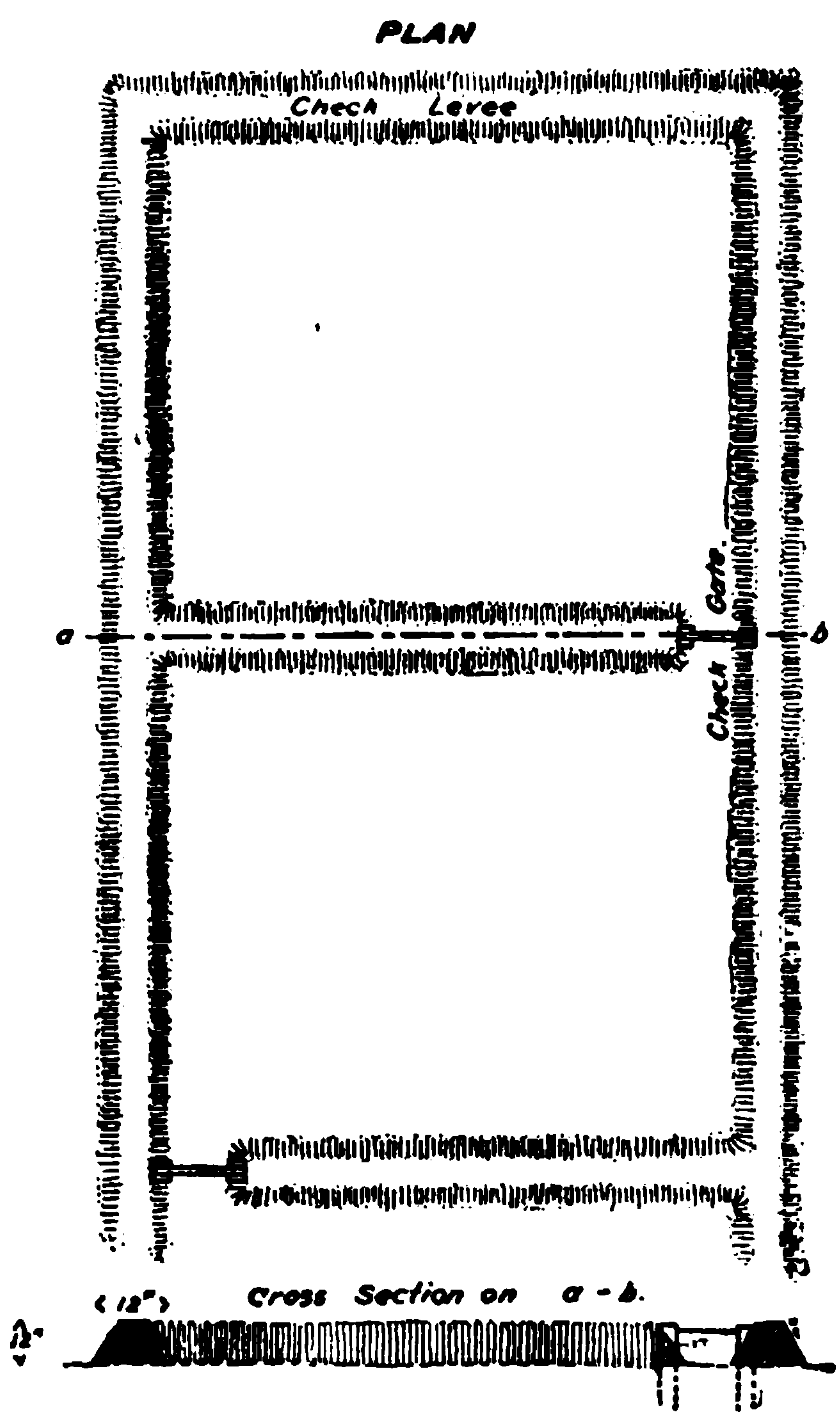


FIG. 52.—Application of water by the block system.

The accompanying figure (52) gives a plan of two rectangular fields connected by a gate set in the levee, so that water can be turned from one field into the other without cutting the banks. This represents a field in southern Arizona, the sides being from 20 to 60 feet in length, and the ridges 10 inches

A. FIELD PREPARED IN RECTANGULAR CHECKS.

B. IRRIGATION BY CHECKS IN SAN JOAQUIN VALLEY, CALIFORNIA.

in height. Alfalfa and other forage crops are grown in such fields.

Many of the early settlers in the Southwest imitated the Mexicans, or employed them as laborers, building checks upon the same general plan, but usually enclosing more ground. Fields of from one acre to twenty acres or more in area have been levelled and surrounded by low levees, from 1 to 2 feet in height and 5 to 10 feet in width. These are made relatively wide at the bottom, in order that the slopes may be gentle, so that mowing machines can be driven over them.

Figure 53 illustrates a modification of this method used in New Mexico. Water is let into the first check-bed from the lateral ditch by means of a box or gate, or by making an opening in the bank with a large hoe. When the first bed is covered, the lower side of the border is opened, and so on until each has been flooded. In practice a number of these beds are irrigated simultaneously, water being let into the rectangles numbered 1, 5, 9, and 13 simultaneously, and then into the beds below them.

Another method of procedure with these beds is to let the water flow through the upper until the lowest is covered to a depth of about 3 inches, then obstruct the opening to this bed and permit the water to accumulate in the next square above, and so on, filling each in succession from the lowest to the highest and allowing the water to soak

away. It is claimed that by following this course the land receives water more uniformly.

For crops such as tomatoes, sweet potatoes, and chili — one of the most important foods of

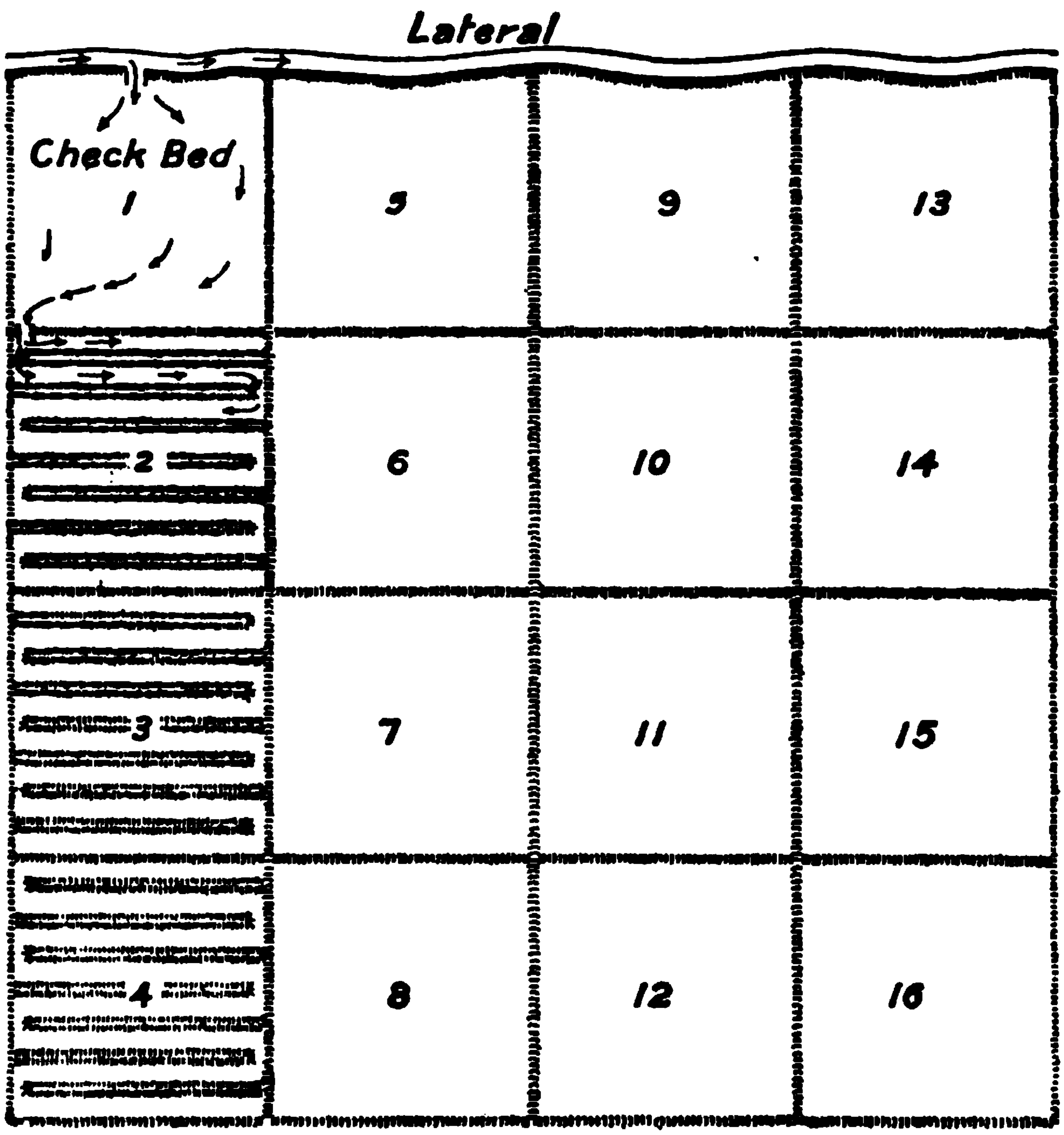


FIG. 53. — Flooding in rectangular checks.

the Mexicans — and for similar plants raised in ridges, a modification is introduced, as shown in squares 2, 3, and 4. Ridges are made in the beds

in such a form that the water is compelled to flow around and along these until the bed is filled nearly to the top of the ridges; then it is let into

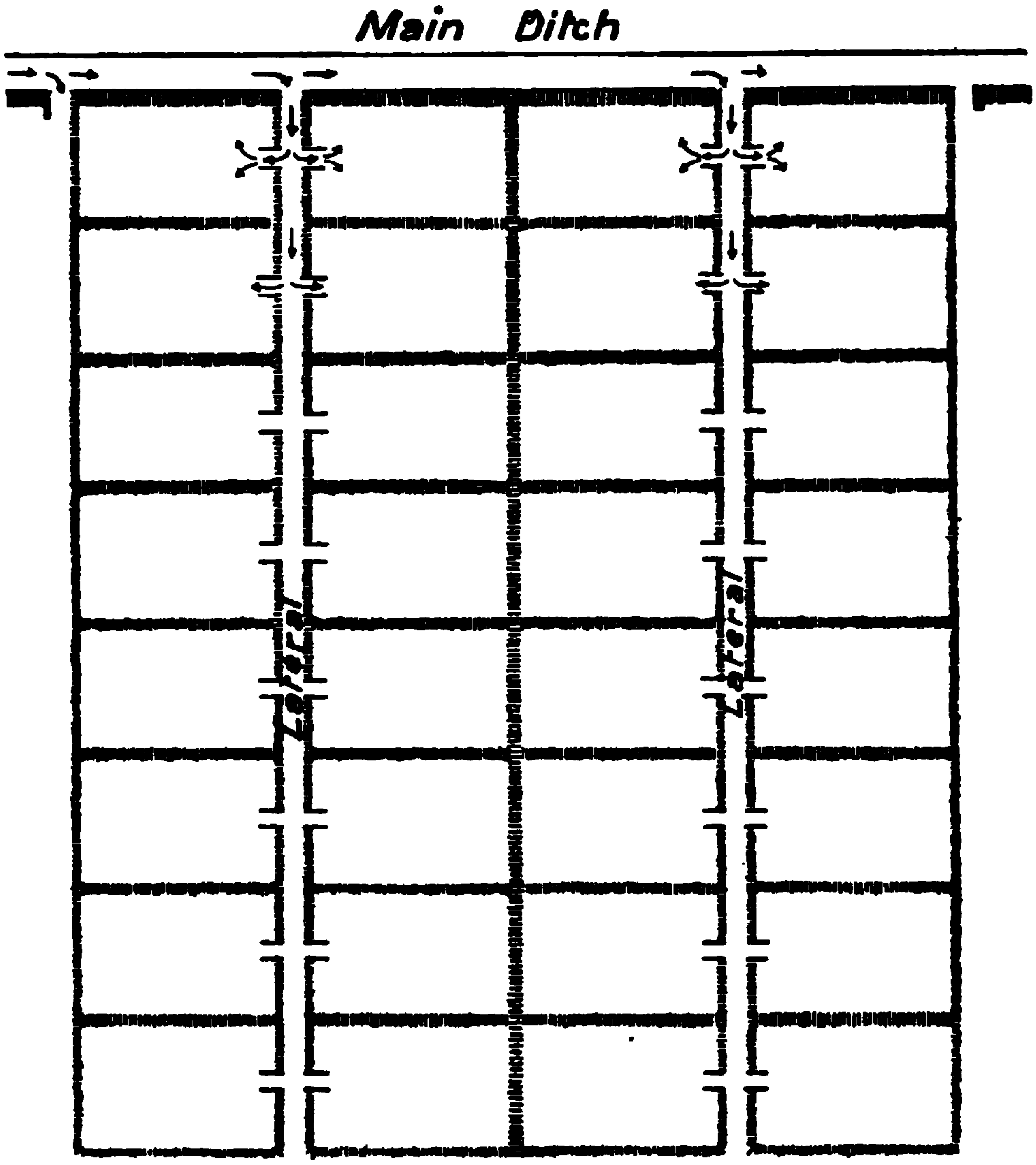


FIG. 54. — Plan of irrigated garden divided into compartments or checks.

the next bed and the operation is repeated. Chinese gardeners also follow this plan.

Instead of turning the water from one bed into

another, it is sometimes customary to provide lateral ditches in such form that the water can flow into each compartment without passing through the other, as illustrated in Fig. 54. In this way washing of the soil is prevented, and the amount can be regulated with great care for each variety of crop.

On land nearly level, but with small inequalities, it has been customary to smooth these off by plough and scraper, or by dragging a heavy iron beam across the field, pulling the hummocks into the hollows. The cost of levelling is usually very great, and it is only for the most valuable crops and orchards that this is done. Where the undulations are of such an extent that they cannot be removed by this method, it is necessary, in order to practise check flooding, to adjust the shape of the banks or levees to suit these conditions. Instead of making them rectangular, the levees are built along the slopes to fit the contour of the surface. The accompanying figure (55) shows how these levees are built along a side-hill slope, and Pl. XXXI, *B*, illustrates a portion of one of these on irregular ground.

The canal brings water to the upper side of the field and follows along on a gentle grade. Below this, at a distance such that a bank a foot or two in height will pond the water back to the side of the canal, a ridge is built. The distance of this ridge from the canal will depend, of course, upon the slope of the ground; if very gentle, the bank

or levee can be 100 feet or more away, while with steeper slopes it must be nearer. A series of such check levees follow, in their course approximately

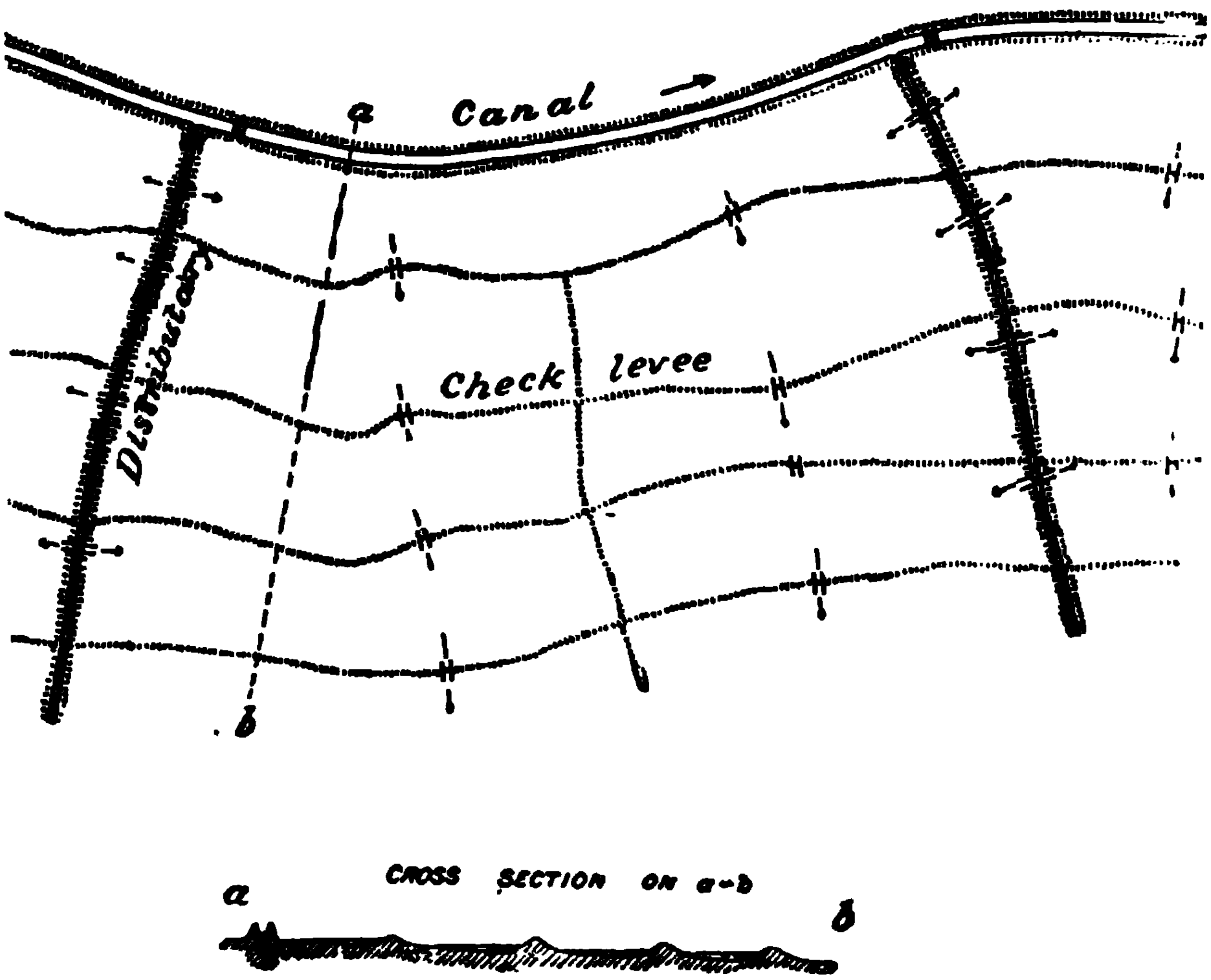


FIG. 55. — Checks on sloping land.

paralleling that of the canal, and make a number of strips, each successively lower, as shown by the section from *a* to *b*. Water is let into these strips by means of small distributary ditches, as shown in the illustration.

WATERING BY FURROWS.

The system of flooding in checks, although originally practised to considerable extent in the South-

west, has gradually been given up, owing to the expense of levelling and leveeing the ground. With experience and acquired skill the irrigator has become able to apply water with economy without resorting to such expensive means. This is particularly true in the application of water to crops which are cultivated in furrows, as, for example, corn and potatoes. The furrows are ploughed in such a direction that a little stream will flow freely down them without washing away the soil.

Water is taken from the main canal, which follows approximately the contour of the surface, into the distributing ditches, which may be parallel with the canal or diverge from it. If the land is nearly flat, the furrows can be run directly away from the distributing ditch from the higher to the lower side of the field. If, however, as shown in the accompanying figure (56), the slopes are steep, the furrows must be ploughed diagonally to the slope, so as to reduce the velocity of the little rills.

Water is turned into a half dozen or more of these furrows, and makes its way gradually toward the lower end. As soon as it has reached this point, the stream is cut off and turned into another set of furrows, and so on until all have been filled. The slope given the furrows determines to a certain extent the amount of water received by the soil. If the fall is very gentle the water moves slowly and a large portion sinks in while the furrow is being filled; if steep, the water quickly passes to the

A. CANVAS DAM IN TEMPORARY DITCH.

B. IRRIGATING A YOUNG ALFALFA FIELD.

lower end and the ground does not have time to absorb as much.

When the entire field has been watered and the surface has become sufficiently dry for cultivation,

FIG. 56. — Application of water by furrows.

the furrows are usually ploughed out and a thin layer of the top soil is stirred to make an open porous covering or mulch, preventing excessive evaporation and allowing the air to enter the ground. Without such cultivation a hard crust may be formed, which, although retarding circulation and apparently impervious, yet permits continual evaporation. The loosening of this crust breaks the capillary connection with the moisture beneath, and thus lessens the loss of water.

The fields of small grain, after sowing, are usually rolled with a device known as a marker. This consists of a heavy roller upon which are projections

so arranged as to make small parallel furrows. These are rolled in the direction of the desired slope, so that the water can flow down the marks through the grain, as it would in furrows through a corn field. The rapidly growing grain shades the surface, and prevents the formation of crust, rendering subsequent cultivation unnecessary even if it were practicable. Instead of a roller various devices are used to make these small furrows, the object being to provide channels for evenly distributing the water.

The ditches are ploughed through the fields and water is forced out of them either by putting in temporary obstructions of dirt, boards, or sheet metal or by a small canvas dam. This latter con-

FIG. 57. — Water turned from furrow by canvas dam.

sists of a piece of stout cloth, one edge of which is tacked to a stick long enough to extend across the lateral ditch or furrow. The canvas, falling into the furrow, fits the sides and bottoms, and is held in place by a clod of dirt thrown upon it. Water

meeting the obstruction still further forces the canvas down, making a fairly tight dam, against which it accumulates and overflows into the field, as shown by Fig. 57. After sufficient water has been turned out at this point, the canvas dam (Fig. 58) is pulled up and carried farther down the ditch, where it is again placed in it and another section of the field is irrigated. This method is illustrated in Pl. XXXII.

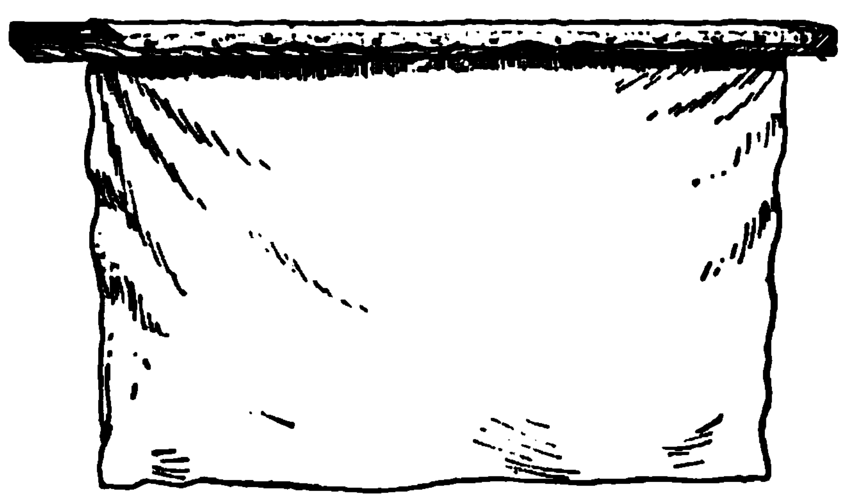


FIG. 58.—Canvas dam.

A drawing of a canvas dam is shown in Fig. 58. There are also given (in Figs. 59 and 60) illustrations of different forms of simple devices for controlling the water flowing in furrows and small ditches, known as tappoons, a word in common use in the Southwest, but not generally employed outside of southern California and Arizona. In Fig. 59 are shown two forms of metal tappoons, these having an oval or rounded outline in order to fit into the furrows. The sheet of metal is pressed down into the soft soil, obstructing the flow. The tappoon is sometimes strengthened by means of a central rib or pin, which projects below, as shown in

the left-hand drawing, and prevents the tappoon from being washed out.

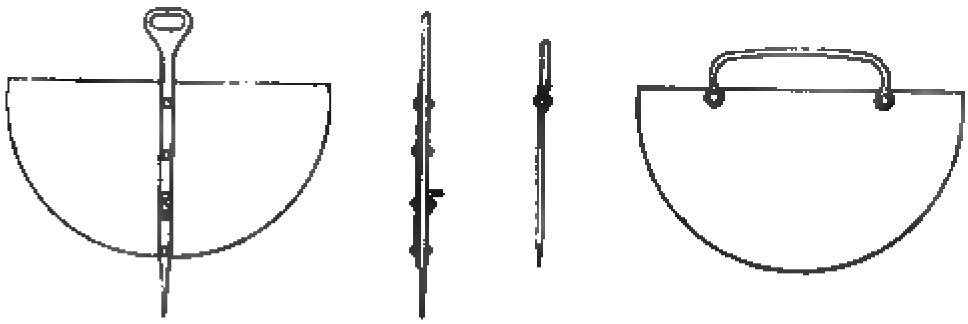


FIG. 59.—Metal tappoons.

These tappoons sometimes consist merely of a board of sufficient width to extend across the furrow. In case it is desired to let a certain amount of water pass this point, one or more holes are bored in the tappoon, these being closed by a plug when not in use.

FIG. 60.—Wooden tappoon provided with outlets.

FIG. 61.—Metal tappoon with measuring gate.

A more elaborate device of this character is shown in Fig. 61, being a small portable metal

FURROW IRRIGATION OF GROVE.

dam or tappoon, with a rectangular opening for measuring roughly a certain quantity of water. This can be provided with a sliding door or gate, permitting the passage of a stream of water of a given number of square inches. If the pressure is maintained at from 4 to 6 inches above the centre of the opening, the delivery can be computed in miner's inches.

WILD FLOODING.

With care it may be possible to dispense with checks or furrows and to apply water with considerable uniformity. For grass land, clover, alfalfa, and similar forage plants it is not feasible to provide furrows, and water must be applied by what is usually known as "wild flooding." That is to say, it is led to the upper part of the field and there turned loose in such a way as to cover the surface with a thin layer. Much care is required to do this, far more than when checks or furrows have been made. To get the water to the right places it is usual to provide through the fields shallow depressions which serve to guide the water. From these it spreads out in thin sheets. The system is illustrated by accompanying diagrams, in which the attempt is made to exhibit the distributing laterals through the fields and the course taken by the water in coming from these.

In Fig. 62 the broken lines are contours, or points of equal elevation. The supply ditch is

seen following along one of these, with gradually descending grade. From this are laterals or temporary ditches following down the leading ridges. On each side of these temporary ditches are slight elevations of the nature of check levees,

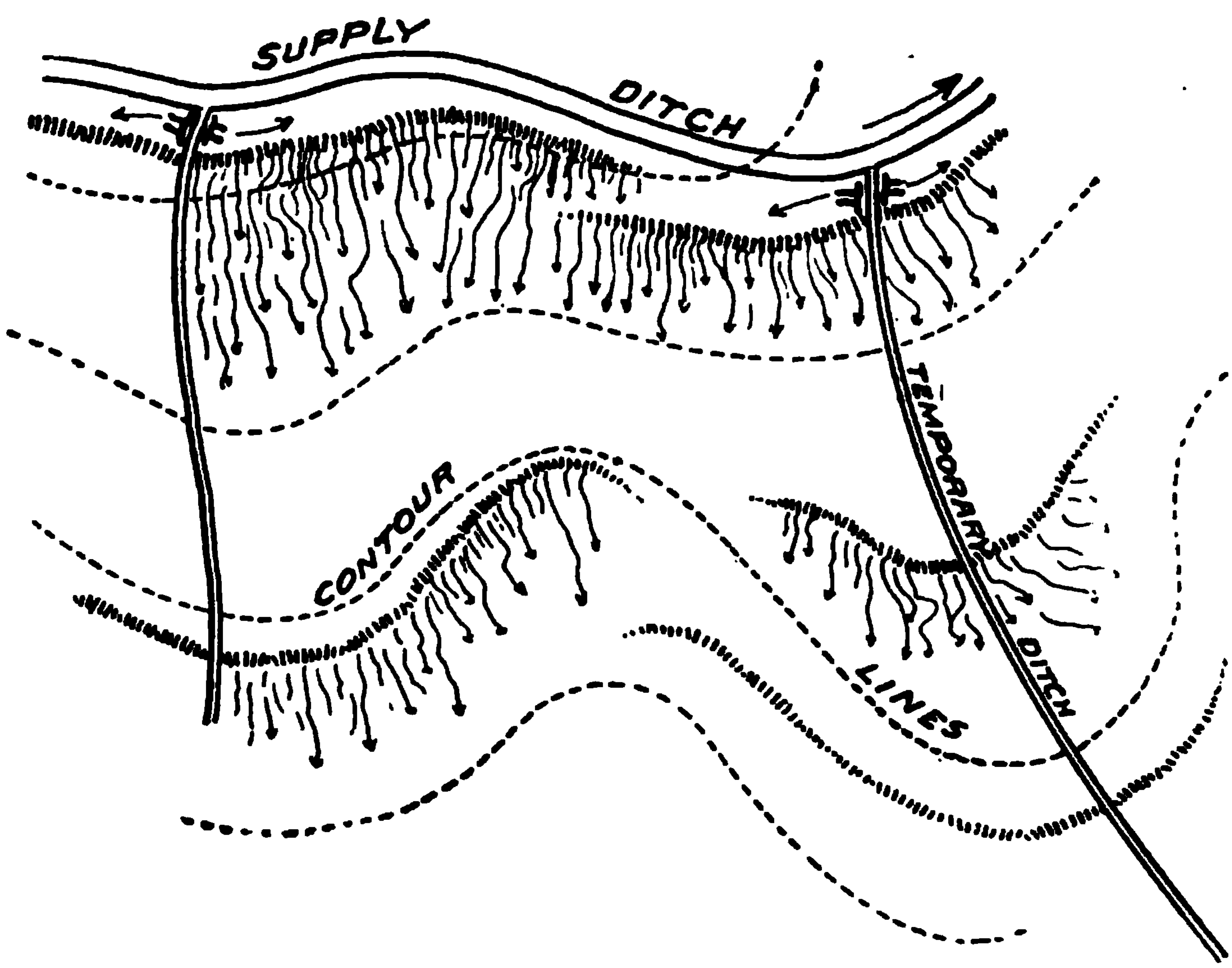


FIG. 62. — Plan of wild flooding.

which tend to throw the water outward along the contours. Spreading along above these, the water gradually overflows and finds its way down the slope in a sheet or numerous rills, as indicated by the irregular lines.

In order to thoroughly wet the field, the irrigator

takes advantage of all the smaller ridges or inequalities, running the water out upon these, and not allowing it to escape into the depressions until it has thoroughly wet the surface. Not all the water will soak into the ground, and the excess

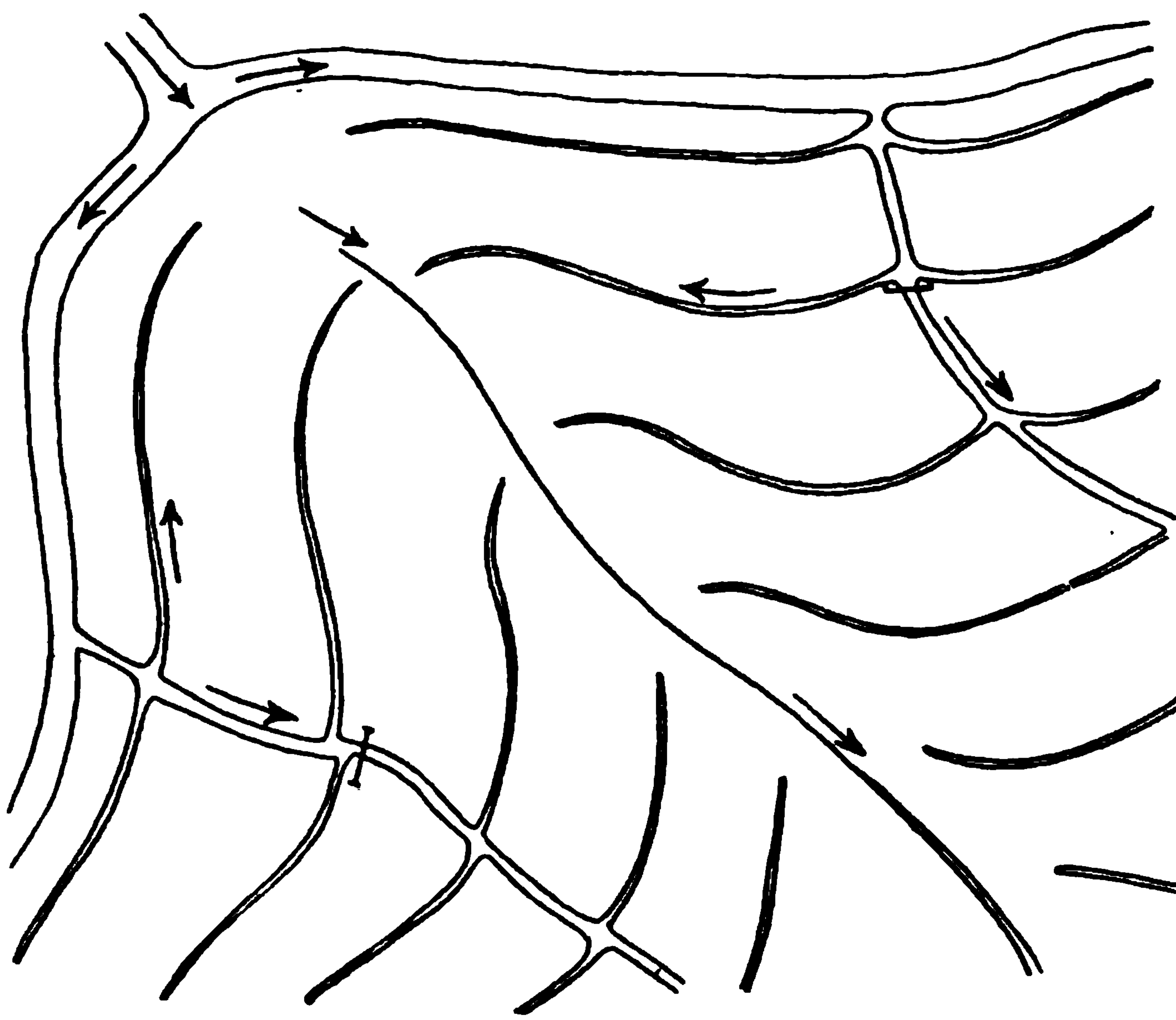


FIG. 63. — Plan of distributing water on rolling lands.

which collects in the depressions is again conducted out along contours to the next lower series of ridges. The general theory of applying water is shown by Fig. 63, where the temporary ditch is subdivided to flow around the head of a slight depression. The direction of the arrows

shows the way in which the streams of water are supposed to be distributed, gradually vanishing into the grass land or cultivated field. A portion of the stream reappears in the depressions, as indicated by the line and arrows in the centre of the drawing. This stream, when it attains considerable size, is gradually conducted out and used on lower portions of the field.

ORCHARDS AND VINEYARDS.

In the localities where the best orchards and vineyards are located, usually water is in greatest

FIG. 64. — Box for distributing water in an orchard.

demand, and extraordinary care must be taken to secure economy in its use. The necessary supply

A. FURROW IRRIGATION OF VINES.

B. FURROW IRRIGATION OF ORCHARD.

is conducted, often by cement-lined ditches and by wooden flumes, as near as possible to the trees and vines, and is then turned out into furrows between the trees as shown on Pl. XXXIII. One of these boxes or flumes is shown in the drawing (Fig. 64). The water, issuing from small apertures in the side of a wooden box, falls into the furrows and is immediately conducted to the vicinity of the trees.

FIG. 65.—Outlet from side of small flume.

The accompanying illustration (Fig. 65) shows the outlet from the side of one of these small flumes or distributing boxes. These small gates are placed at intervals of from 3 to 5 feet or more, and a number of them are opened at a time, each delivering water into a furrow. These furrows having received a sufficient quantity, the small gates are closed and another set opened.

Some irrigators still adhere to the method of irri-

gating trees in small pools or basins, although this is not regarded as desirable because of the tendency of the roots under these conditions to develop near the surface. It is claimed, however, that water can be more economically used in this way. The following figure (66), made from a photograph taken in an orchard near Los Angeles,

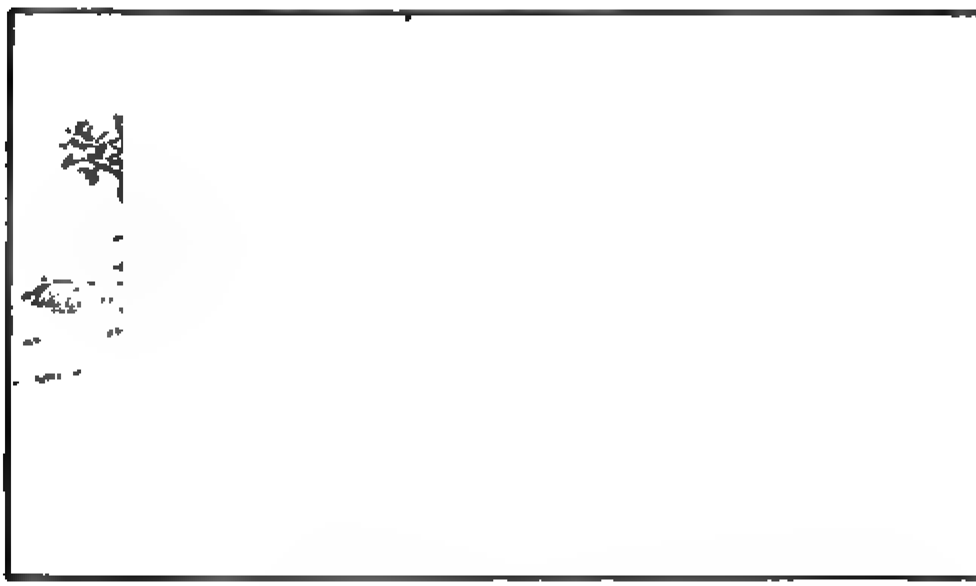


FIG. 66. — Orchard irrigation by pools.

California, shows the lower end of a system of small basins into which an orchard is divided.

The soil on the side-hills is often excellent in quality for the production of fruits, and the elevated portions of a valley are frequently freer from frosts than the bottom lands. For this reason orchards have been set out on sloping lands, and methods of irrigation have been adapted to the ground. The next figure (67) shows one

of the ways in which a small stream of water is conducted down the slope. If allowed to flow freely this would wash for itself a deep channel. It is therefore confined in a small wooden flume, dropping vertically at short intervals. Along the horizontal portions of the flume small outlets are arranged, and water is taken from these into furrows leading along the contour of the ground.

FIG. 67. — Irrigation on slope with stepped flume.

Care is usually taken that the water shall not actually touch the tree trunks; it is kept far enough away to wet the ground within the radius of the roots, to encourage these to spread outwardly as far as possible. After the water has traversed the furrows through the orchard until it has reached the far end, the supply is cut off, and the ground is tilled as soon as the surface dries sufficiently.

On Pl. XXXIV are given two views, the upper one, *A*, being of furrow irrigation of vines, and the lower, *B*, of similar methods of irrigating a young orchard. In both of these views water is shown as applied lavishly, especially in the lower, where the soil is apparently being washed away. Such use of water is possible only where large amounts are to be had, although even where there are small quantities it is sometimes economical to store this in small tanks or reservoirs and run out a large volume at once, in order to give the ground a thorough wetting; by so doing the water can be distributed more uniformly to all parts of the orchard. The course of the water is being directed by the irrigators, who by means of long-handled shovels keep the furrows open or close them by throwing in clods of earth, constant attention being given to the course of the water, so that it will not accumulate in depressions.

The next view, Pl. XXXV, shows a young orchard for which a distributing system, designed for permanence and economy of water, has been constructed. The distributing ditch is of cement and is provided with a series of drops or small falls and gates by which the water can be raised and forced to flow out through small apertures in the sides. The character of the cultivation which follows the application of water is shown by a view of a more mature orchard, Pl. XXXVI.

CEMENT-LINED DISTRIBUTING DITCH.

SUBIRRIGATION.

In order to reach still greater economy, attempts have been made to conduct the water beneath the surface immediately to the roots of the trees, thus preventing waste by evaporation from the surface of the ground. Various devices have been tried, but few of these have been successful, owing to the fact that the roots of the trees rapidly seek out the source of water and develop there, entering the openings from which the water issues, or surrounding the pipe by a dense network. Porous clay tiling has been laid through orchards, and also iron pipes perforated so as to furnish a supply of water along their length. A machine for making cement pipe in place has also been invented and successfully used. Small trenches are dug through the orchard between the trees, and the pipe-making machine deposits the material in the trench, which is filled as soon as the cement is set. Water is thus distributed underground where needed.

In a number of orchards where the subsurface irrigation has been unsuccessful because of the roots stopping up minute openings beneath the surface, the system has been reconstructed and water brought to the surface at or near each tree by means of small hydrants, shown in Fig. 68. Vertical pipes are placed at short intervals, leading to the level of the ground, and in these are small

iron gates or shutters so arranged that the flow can be cut off in the buried pipe. Pushing down one of these gates, the water rises and overflows the surface until a sufficient amount has been obtained. This gate is then raised and the next is pushed down, and so on until water has been caused to overflow at each point in succession down the slope of the ground.

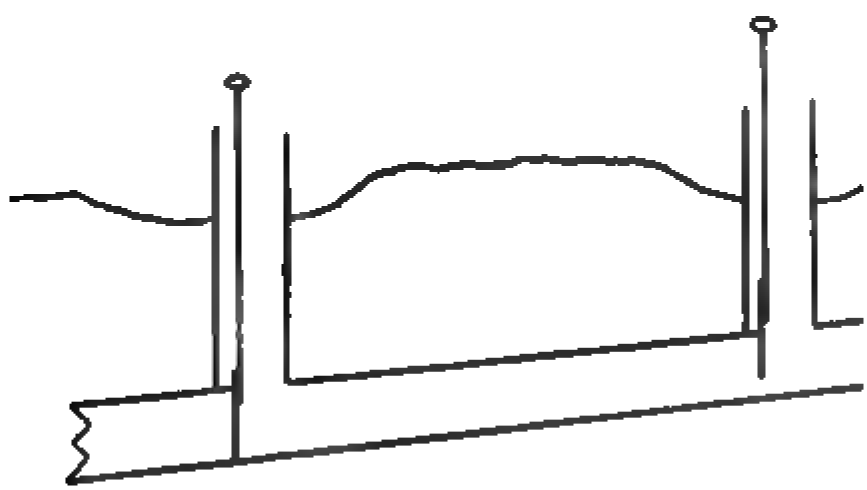


FIG. 68. — Pipes and hydrants for distributing water in an orchard.

For annual or root crops subirrigation has been successfully practised by the use of the small perforated pipes, which allow a small amount of water to escape at short intervals. These pipes are laid 12 inches or more beneath the surface, and are connected with lines of tile leading from the reservoir or source of supply. As the crops are removed each year and the ground cultivated, the roots do not have an opportunity of entering and stopping the pipes.

The accompanying illustration (Fig. 69) is a plan of one of the small systems of subirrigation devised and successfully used by a Kansas farmer, and is given as being typical of a number of devices of this kind. The 3-inch tiles are laid 15 inches below the surface and 10 feet apart. The joints are closed with cement, with the exception of about an inch on the under side of the tiles, a small amount of water escaping at this point. In the construction $2\frac{1}{2}$ acres were laid and cemented in ten days. Water is supplied to the tiling at the rate of about 20 gallons per minute. The grade is such that the tiling acts as a drain if at any time too much water is received from rainfall. The success of such an undertaking depends largely upon the character of the subsoil, as well as of the soil itself. If the subsoil is extremely porous, the water may sink away with-

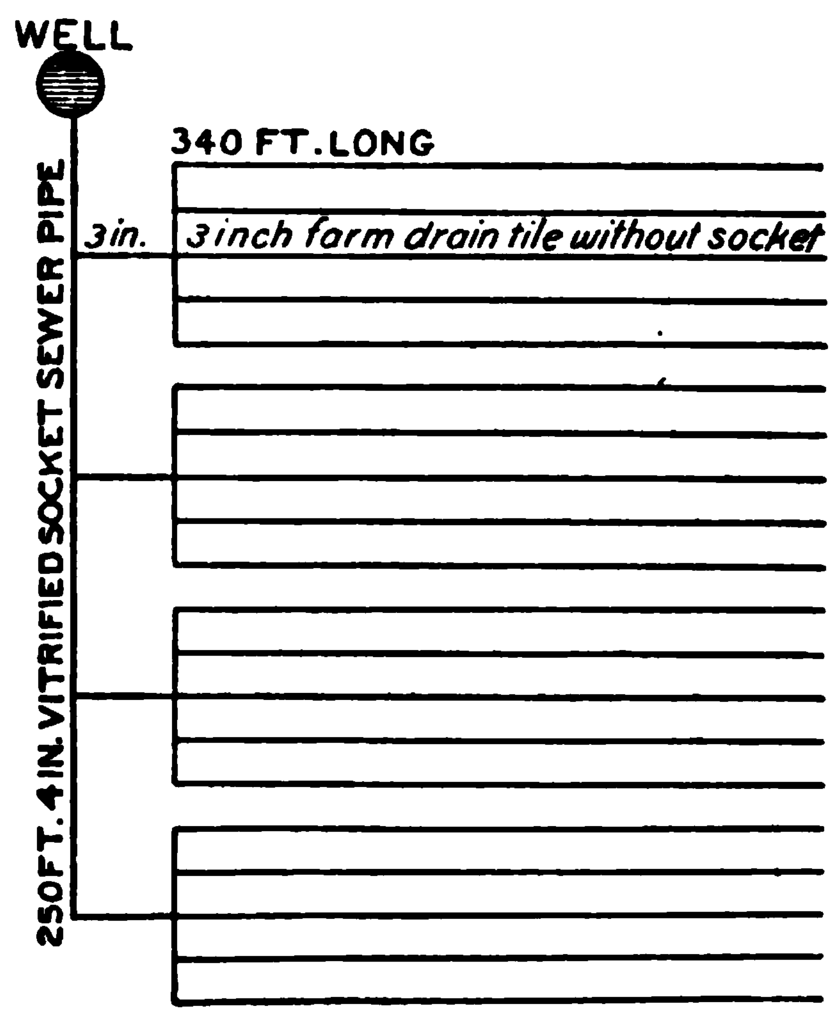


FIG. 69. — Plan of subirrigating system.

out reaching the surface. Where the structure is such that the water is transmitted horizontally, these systems of subirrigation have been used to great advantage.

A common mistake made in constructing these subirrigation systems has consisted in giving the pipes an inclination so great that the water runs immediately to the lower end, and does not saturate the ground uniformly. The pipes should be laid nearly horizontal. Sometimes the pipes have been buried too deep in a clayey subsoil and the water would not spread laterally until the pipes were raised nearer the surface.

For the purpose of subirrigating, tile is preferred, as being permanent, but other material has been used, such, for example, as galvanized sheet iron, this being laid with an open seam at the bottom, as shown in Fig. 70. The opening is made smaller than indicated by the drawing, so that the water will not escape with too great rapidity. In a number of instances the increased yield of a single crop has more than repaid the cost of a subirrigation system. Where the conditions are favorable the economy resulting in distribution of water in this way is very great. There is no loss by

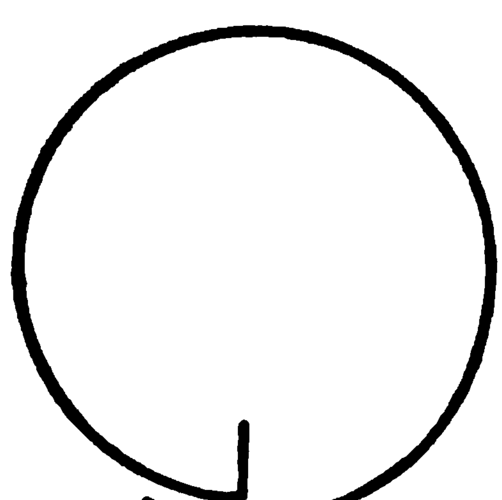


FIG. 70.—Section of small galvanized sheet-iron pipe.

direct evaporation or by wetting soil at a distance from the growing plants.

The term "subirrigation" is occasionally applied to conditions occurring in nature such that water percolates freely beneath the surface of the ground for considerable distances in a sheet sufficiently near the surface to supply the need of crops. The ground is not actually saturated, but sufficient moisture is transmitted to nourish the plants without drowning or waterlogging the soil. These subirrigated areas, so-called, are often located in broad valleys along a stream from which the water finds its way outward beneath the surface. They are also occasionally found upon gentle side slopes, the moisture coming from some stream or canyon and tending to form springs near the edge of the valley.

Where the subsoil has a texture such that it transmits water freely, the building of irrigation ditches may subirrigate large tracts of country without rendering them marshy. Such conditions are found, for example, in the vicinity of St. Anthony, Idaho, where certain farms obtain an ample supply of water from ditches a half mile or more away, without the necessity of distributing small streams over the surface. Also in the vicinity of Fresno, California, vineyards are maintained in good condition, although water has not been visibly applied for many years. The closing of the ditches would, however, result in gradual drying up of the ground, and the farmers benefited by subirrigation must

of necessity pay their share of the cost of maintaining the ditches, although they do not receive water directly.

This process of subirrigation gradually merges into swampy conditions, and it occasionally happens that the lower part of a subirrigated field must be drained to remove the excess of water. This can be done either by gravity ditches or by pumping devices, sometimes the water in the ditches being utilized to actuate water wheels, each in turn operating suitable machinery for taking the excess from the low points. Where electric power can be had at small cost, pumps have been erected to bring the excess water from underground and make it available for the irrigation of fields otherwise dry. In portions of the San Joaquin valley of California, where electric transmission lines have been constructed leading from the water power stations in the canyons, small centrifugal pumps are thus utilized, the motor being on the upper end of the shaft carrying the pump. Lands can thus be drained and water provided for use elsewhere. Even in localities where the water is 20 or 30 feet or more beneath the surface, it has been pumped by electric power at a cost far less than is paid for the ordinary gravity supply.

AMOUNT OF WATER APPLIED.

The amount of water required for raising crops varies according to soil and other conditions, as

noted on a preceding page. The plant itself needs a certain minimum supply in order to receive and assimilate its food and to keep up transpiration. A far larger quantity is required to saturate the surrounding soil to such a degree that the vitalizing processes can continue. The soil is constantly losing water by evaporation and by seepage, so that the amount which the plant takes from it is relatively small. Nevertheless, the moisture must be maintained within narrow limits in order to produce the most favorable conditions of plant growth.

Experiments have been made to determine exactly how much water is needed in order to keep the soil in proper condition for plants of different character. Among the most important investigations are those by Professor F. H. King of Madison, Wisconsin, who has found by direct measurement that from 300 to 500 pounds of water are required for each pound of dry matter produced. In other words, for each ton of hay raised upon an acre 300 to 500 tons of water must be furnished either by rainfall or by artificial means.

Water covering an acre one inch in depth weighs about 113 tons, and to produce one ton of hay the depth of water required is approximately from 3 to 5 inches. It is necessary to furnish at least this amount, and sometimes several times as much, in order to produce a crop. The actual amount used in producing 5 tons of barley hay

to the acre has been about 20 inches in depth. Much depends upon the permeability of the soil, and its ability to hold water.

The quantity of water used in irrigation is usually stated in one of two ways—either (1) in terms of depth of water on the surface, or (2) in quantities of flowing water through the irrigating season. The first method is preferable, since it is susceptible of more definite consideration, and is also more convenient for comparison with figures for rainfall, which are given in inches of depth. In the humid regions rainfall is usually from 3 to 4 inches per month during the crop season. In the arid region, where the sunlight is more continuous and the evaporation greater, there should be, for the ordinary crops at least, enough water during the growing season to cover the ground from 4 to 6 inches in depth each month. Carefully tilled orchards have been maintained on far less. In Arizona, where the crop season is longest, being practically continuous throughout the year, twice as much water is needed as in Montana, where the crop season is short and the evaporation is less.

The second method of stating the quantities necessary for irrigation is of convenience when considering a stream upon which there is no storage. It is frequently estimated that one cubic foot per second, or second-foot, flowing through an irrigating season of 90 days, will irrigate 100 acres. One second-foot will cover an acre nearly 2 feet

deep during 24 hours, and in 90 days it will cover 180 acres 1 foot in depth, or 100 acres to a depth of 1.8 feet, or 21.6 inches. This is equivalent to a depth of water of a little over 7 inches per month. In several of the states laws or regulations have been made to the effect that in apportioning water not less than 66⅔ acres shall be allowed to the second-foot of continuous flow. This is extremely liberal, and permits extravagant use of water.

When the ground is first irrigated enormous quantities of water must sometimes be used in order to saturate the subsoil. It has frequently happened that, during the first year or two, a quantity of water which would cover the ground to a depth of 10 to 20 feet has been turned upon the surface. Frequently for several years an amount equal to a depth of 5 feet or more per annum is thus employed. Gradually, however, the dry soil is filled, and, as stated in another place, the water table is raised nearer the surface, less and less water being needed.

The farmers, being accustomed to the use of large quantities of water, often find it exceedingly difficult to get along with less, and continue to use excessive amounts, often to their own disadvantage. They are actuated in part by the consideration that, having paid for the use of the water, they are entitled to a certain quantity, and fear that if they do not take all of this their claim to it may be dis-

puted. Some of them actually waste water to their own detriment from the mistaken belief that in so doing they are establishing a perpetual right to certain quantities.

With the gradual development of the country and the bringing of more and more land under ditches, the need for water increases, and equity demands that no irrigator shall take more than he can put to beneficial use. Flowing water must be considered as a common fund, subject to beneficial use by individuals according to orderly rules, each man taking only the amount he can employ to advantage. Under any other theory full development of arid regions is impossible.

It is instructive in this connection to know what is the least amount of water which has been used with success. To learn this, it is necessary to go to Southern California, where, as stated on previous pages, the supply of water is least, relative to the demand made upon it, and the economy is correspondingly greatest. Successive years of deficient rainfall in California, from 1897 to 1900, while working many hardships, served to prove that with careful cultivation crops, orchards, and vineyards could be maintained on a very small amount of water. In some cases an amount not exceeding six inches in depth of irrigation water was applied during the year, this being conducted directly to the plants, and the ground kept carefully tilled and free from weeds.

CULTIVATION AFTER IRRIGATION

During these times of drought some fruits, as, for example, grapes, apples, olives, peaches, and apricots, were raised without irrigation, but a most thorough cultivation, as shown on Pl. XXXVI, was practised. Some fruit growers insist that, in the case of grapes, for example, the quality is better when raised without artificially applying water, although the quantity is less. It has been stated that in raisin-making there is less contrast than might be expected between the irrigated and non-irrigated vineyards, for although the yield of grapes raised by watering is far heavier, yet after drying the difference is not so marked. Wheat and barley, also, according to some farmers, make a better hay when cultivated dry, but the weight is less. Shade trees, such, for example, as the eucalyptus or Australian blue-gum, the catalpa, mulberry, and acacia, grow without water artificially applied, but do not reach the extraordinary development that they do when near irrigating ditches. It is almost useless to attempt to raise the citrus fruits without plenty of water.

The quantity of water necessary to irrigate an acre, as estimated by various water companies in Southern California, ranges from 1 miner's inch to 5 acres to 1 miner's inch to 10 acres, the miner's inch in this connection being defined as a quantity equalling 12,960 gallons in 24 hours, or almost exactly 0.02 second-foot, this being the amount which has been delivered under a 4-inch head,

measured from the centre of the opening. Under this assumption 1 second-foot should irrigate from 250 to 500 acres. This is on the basis of delivering the water in pipes or cemented channels in the immediate vicinity of the trees or vines to be irrigated.

If it is assumed that 1 miner's inch is allowed for 10 acres, or 1 second-foot for 500 acres, this quantity of water flowing from May to October, inclusive, will cover the ground to a depth of a little over $\frac{7}{10}$ of a foot, or 8.8 inches, a quantity which, with the care and cultivation usually employed, has been found to be sufficient for some orchards. Mr. W. Irving, Chief Engineer of the Gage Canal, Riverside, California, states that for the year ending September 30, 1899, water ranging in depth from 1.78 to 2.48 feet was used in addition to the rainfall of 0.47 foot. This was less than the usual quantity, economy being enforced by shortage of supply.

The method of applying water governs to a large extent the amount used. In the case of alfalfa, flooding is usually practised; with small grains in most parts of the West the water is run in furrows; while in the case of orchards the water is sometimes applied directly to each tree. In this case a little earth basin, about 6 feet or more across and 6 inches deep, is formed around each tree and partially filled with water as shown in Fig. 66. The better way, however, is that of running water in furrows, four or five of these being

ploughed between each two rows of trees. The water is applied very slowly, several days being spent in watering 5 acres, and when dry the ground is thoroughly cultivated.

The annual charges for water by the acre in Southern California, where this economy of water is practised, have been as low as $3, and from this rising to $6 or more per acre. In the case of the San Diego Flume Company it is stated that water was sold for $600 per miner's inch, with an annual charge or rental of $60, 1 miner's inch being considered sufficient for from 10 to 20 acres. The annual charge for water taking the arid region as a whole has averaged by states from 50 cents to $2.00 per acre, or $1.25 per acre for the entire country.

The conditions in Southern California, while they may be considered as exceptional, yet indicate the limiting or ideal conditions of economical use of water. For good farming in other parts of the arid region, 12 inches of water in depth during the crop season should be sufficient, except in the case of alfalfa and other forms of forage which are cut a number of times, when at least from 4 to 6 inches should usually be given to a cutting. As previously stated, the character of the soil, the temperature, and the wind movement introduce so many conditions that broad statements of this kind are merely suggestive, and not to be followed as rules.

Irrigation is usually carried on during the daytime, and it is unusual for water to be applied during the night, other than to arrange the head gates and allow the water to flow to certain portions of the field. In times of scarcity, however, when water can be had only at certain hours, night irrigation must be carried on, and the water carefully applied, with as much skill as possible in the darkness. Night irrigation, although possessing disadvantages, has many advocates. The air being cooler, excessive evaporation is checked, there is less loss and consequently more economy in use, and the plants are not so suddenly chilled as during the heat of the day when cold water is run upon the fields; and the proportional amount of water received during the night is often greater than during the daytime, and the charge or cost is correspondingly less; so that, for economy in various directions, night irrigation is sometimes preferred.

ARRANGEMENT OF IRRIGATED FARM.

The accompanying drawing (Fig. 71) gives the general arrangement of a farm under irrigation. The main ditch is shown in the upper right-hand corner, this being the highest portion of the land. In this angle is the garden, the root crops being shown as cultivated in furrows. Near this is the orchard, so laid out that the water flows along the trees set on contours, this portion of the land being

FIG. 71. — Plan of an irrigated farm.

FIG. 71. — Plan of an irrigated farm.

on a slight side-hill. Farther down another part of the orchard is more nearly level, and the trees are arranged in straight lines. Adjacent to the orchard is a crop of corn, which is irrigated in rows.

Running irregularly through the farm below the orchard is a distributing lateral connected with the main ditch, but receiving also any excess water from the higher land. From this distributing lateral water is taken out at short intervals into the alfalfa and wheat, both of which are irrigated by flooding. Below this land in turn is shown another lateral in the lower left-hand corner of the drawing, this receiving any excess water and carrying it to other fields.

As a result of continued irrigation, the ground water in the vicinity of the farm is gradually raised, and soon after irrigation has been introduced the amount needed annually decreases rapidly by reason of the gradual saturation of the subsoil. This is shown diagrammatically in the accompanying figure, which gives a plan of another farm and a section showing the condition of the ground. In the plan, Fig. 72, is shown a main canal flowing diagonally across from left to right. Lateral ditches are taken out of the main ditch and carried along two sides of the farm, this being possible because of the slope, indicated by the contours. From these lateral ditches on the two sides, distributing ditches flow inward toward the main

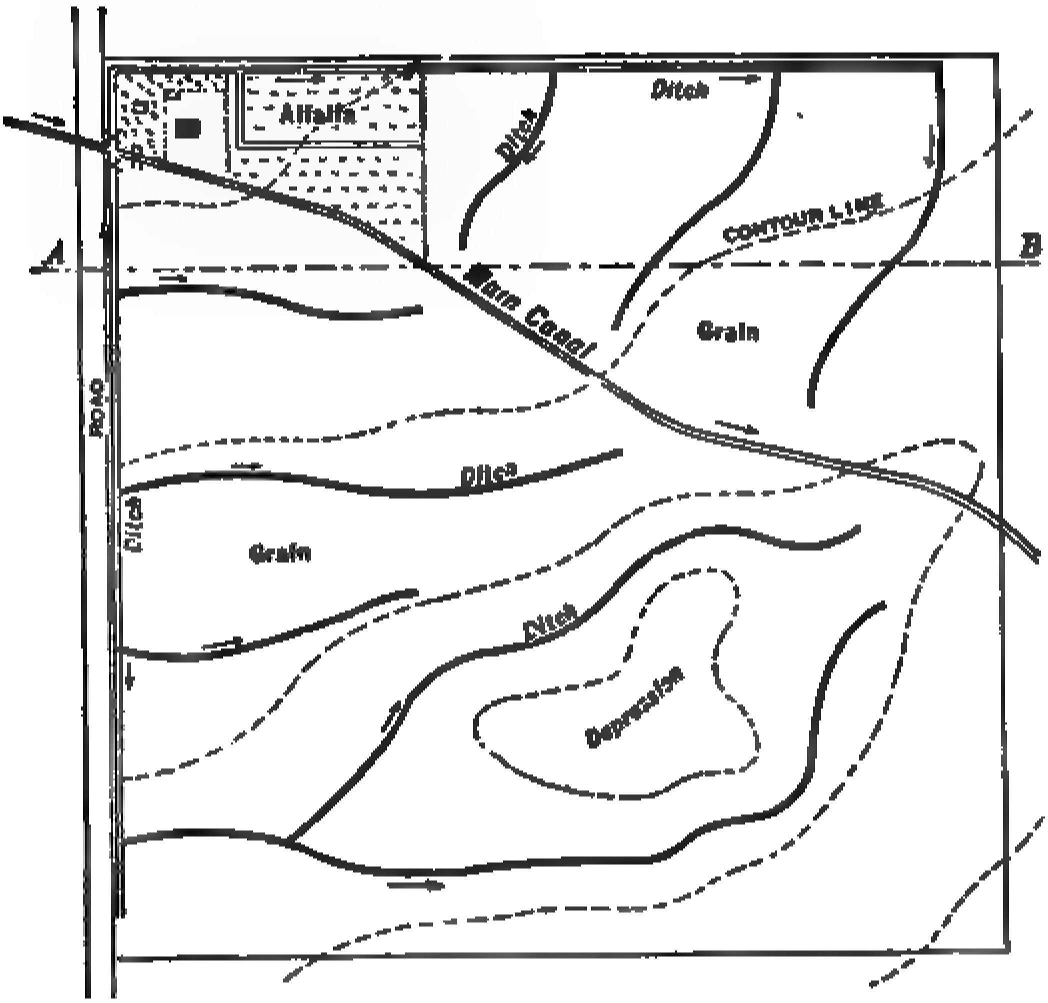


FIG. 72. — Rise of ground water following irrigation.

canal, following in a general way along the contours. One of these ditches forks to embrace a depression, so that water can be carried toward this from both sides. Consequent upon irrigation being carried on continuously, the ground water, which previously was from 15 to 18 feet beneath the surface, has been raised to within 6 or 8 feet of the surface, as shown by wells. During the irrigating season the water is brought still nearer the surface, as indicated in Fig. 72.

In a case of excessive use of water and seepage from higher lands, this gradual rise may become destructive by waterlogging soil or forming marshes. The most serious dangers from this cause are the liability of producing disease in plant roots if permanently submerged, and of bringing alkaline salts to the surface. This matter is further discussed on pages 76 and 281.

CHAPTER VII.

UNDERGROUND WATERS.

In the preceding pages consideration has been given mainly to the water which flows on the surface of the earth, in the form of creeks or rivers, or stands without apparent motion in ponds. It is important, however, not to neglect the waters which, although out of sight, are circulating beneath the surface, and which, in the aggregate, play an important part in the reclamation of arid land as well as in various industries. In the humid region the ground is usually saturated with water nearly to the roots of the trees. In the arid region, however, the plane of saturation, or water table, as it is termed, may be at great depth. Water applied to the surface tends to sink to the lowest possible level, but may be prevented from so doing by an impervious layer. Beneath the irrigated fields there sometimes exists a thickness of several hundred feet of dry rocks, but, as a rule, these are in time filled with water, and an underground circulation is set up comparable to that existing in humid countries.

RETURN WATERS.

In the process of irrigation, a portion of the water applied to the fields evaporates. Another portion is taken up by the plants and escapes to the air through the leaves; this is the part that has done the work for which water was obtained and applied. Another portion sinks into the ground and gradually passes out of the reach of the plants by percolating downward or outward from the fields; this portion is practically lost to the irrigator, and represents a certain amount of wasted material. It is sometimes impracticable to guard against this waste; but, as a rule, it may be said that water escaping over or beneath the surface indicates poor management.

The water percolating beneath the surface is not only itself, for the time being, lost, but it is likely to carry with it in solution valuable earthy salts or plant food, washing out and reducing the richness of the soil. Sometimes this washing is of value, as when the soil contains an excess of soluble alkali, and it is desired to get rid of the injurious superabundance.

This underground water gradually travels by percolation or seepage along the path of least resistance, filling up the voids and gradually accumulating until it has raised the level of the water plane to the point of overflow. It seeks the lowest points, these being usually along the drain-

age lines of the valley. Here the water again comes to the surface, after a lapse of weeks or months, forming wet places or springs, and augmenting the flow of a stream. Thus it happens that some of the water taken out in a canal during the time of spring floods from a point higher up on a river may reappear in late summer at a lower point along the river, after having travelled underground a distance of several miles. This seepage or return water, if not heavily charged with alkali, may have especial value, as discussed on page 76. At this late season of the year the streams are naturally at their lowest point and water is in greatest demand.

The accompanying diagram (Fig. 73) shows the conditions which were found during a season in Ogden Valley, Utah. The space from left to right represents the time from July 5 to August 30, 1894. The distance vertically indicates the quantity of water. The dotted lines show the amount of water used in irrigation; this gradually diminishes from about 150 second-feet on the 5th of July to 44 second-feet at the end of August. The inflow coming into the head of the valley is shown by the light line, being about 165 second-feet on July 5, and decreasing to a little less than 75 second-feet. The amount used for irrigation deducted from the inflow should apparently give the outflow from the valley. On the contrary, however, the latter, as shown by the heavy line,

was, almost without exception, greater than the amount coming into the valley, notwithstanding that most of the inflow was diverted upon the fields.

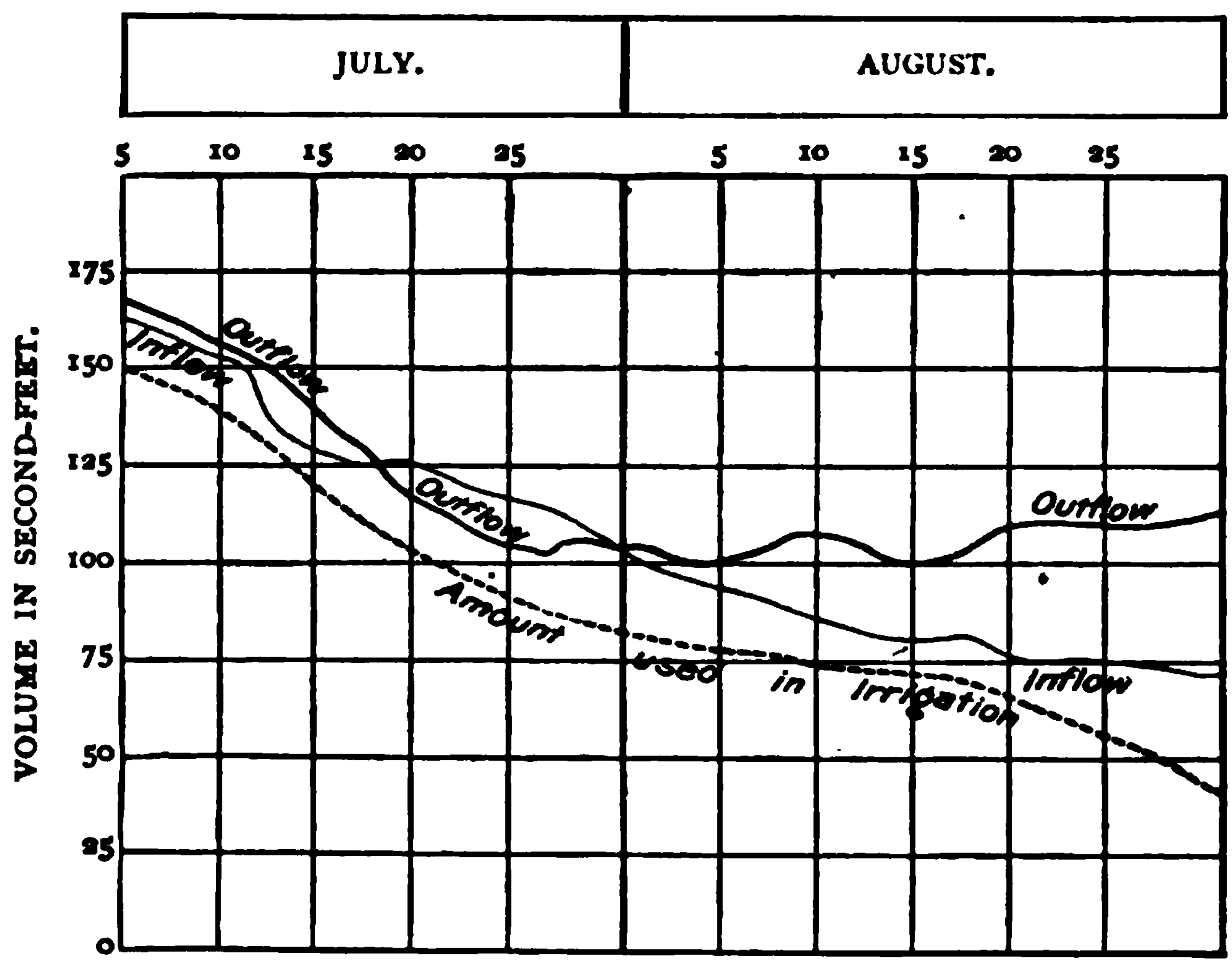


FIG. 73.— Diagram illustrating inflow and outflow of Ogden Valley, Utah.

From the inspection of this diagram it is apparent that the outflow of the valley was increased by the seepage or water applied to the fields during earlier months. As the inflow and the amount of water used in irrigation diminished, the outflow steadily increased.

Because of this large amount of return or seepage water, there may exist the anomalous condi-

tion of a tight dam across a river, taking out all of the stream, and a few miles below the dam pools of water beginning to occur, while farther down these pools overflow and imperceptibly a stream of considerable size appears in the channel, this again being taken out by another tight dam, and so on for a number of times in succession.

The amount of land irrigable along an extensive river system is thus slowly increased, since the water used in early spring in higher valleys may gradually reappear below and furnish water for fields which otherwise would be dry. Thus when the limit of irrigation has apparently been reached, there is found to be still a little more water, the irrigable area widening slowly with the gradual development of irrigation and larger use of water higher on the stream. This irregularity of the rivers, increasing without visible cause, has been noted on page 73.

UNDERFLOW.

Water beneath the surface, generally recognized as occurring in all regions of abundant rainfall, has attracted especial attention when found in arid or semiarid regions, because of the striking contrast with surface conditions. In view of the dryness of the climate and the apparently impervious condition of the sod cover, it did not seem possible, when first noted, that this water could come from local rainfall. For several years preceding and

succeeding 1890 attention was drawn to the fact that upon portions of the Great Plains, where the climate is very dry, there are beneath the surface considerable bodies of water-bearing sands and gravels. These are mainly in the broad valleys occupied by intermittent streams. The mistaken assumption was made that this water must have come from the Rocky Mountain region, and is travelling in a broad sheet with continuous flow toward the southeast. The average fall of the plains is not far from 7 feet to the mile, and it was asserted that in consequence of this slope the water was steadily moving as a vast underground river from the mountains toward the Mississippi.

Assuming that an underflow of this character existed, it was argued that if a channel were cut into the ground, following up a valley having a slope of 7 feet to the mile, but with a rise of only 1 foot in a mile, at the end of the first mile the ditch would be 6 feet below the surface, and in 10 miles it would be 60 feet beneath the surface. On this slope the water would readily run out of the drain, and thus the underflow would be intercepted and brought to the surface. Many thousand dollars were spent in attempting to construct such underflow ditches, but none of these have been successful.

Nature has already trenched the plains with drainage lines of this character, but none of them deliver any considerable amount of water. It is

true that there are occasional springs in the sides or bottoms of these gullies or coulées, but the resistance to the flow underground is so great that the water does not percolate freely toward outlets of this character. The plane of saturation, or water table, follows to a certain extent the undulations of the ground, and is not maintained horizontal, as would be the case if the water stood in an open lake or pond.

To illustrate this point we may assume that a pond is filled with gravel and sand. The surface of the water at first is perfectly horizontal from one side to the other. Before the gravel is placed in the pond the water can be drawn down and will maintain this level surface, except for an infinitely small slope dependent upon the rapidity with which the water is drawn out. After the gravel is thrown in and the outlet is opened, water will rush out, but, owing to the restricting influence of friction, the surface of the water within the gravel will no longer be level, but will assume a decided slope toward the outlet. In course of time this slope will decrease and tend to approach the horizontal, but if a small amount of water is added gradually at the upper edge and an equal amount is running out at the lower point, there will be permanently maintained a sloping water surface within the gravel.

The so-called underflow of the plains consists of the small amount of water which enters the ground

from occasional local rains and which progresses toward lower points at the rate of a few feet a year. Some of this water gradually escapes into the natural ravines, or occasionally bursts forth as a spring; but the plane of saturation of the pervious rocks is not horizontal; it follows often the slopes of the surface of the ground, and sometimes is inclined at a high angle. The digging of a trench into this saturated layer introduces a change in the slope of the water surface, making it dip toward the new outlet. The total amount obtained as a continuous flow rarely repays the cost of the work.

There are, however, localities where underflow works are successful, and it is because of the excellent results attained here that men have argued that such undertakings can profitably be entered upon elsewhere. But the conditions which make it possible to obtain water from under ground are radically different from those existing upon the Great Plains. There the gravel beds or other pervious strata are widespread, and are not usually bounded by well-defined walls. When, however, gravels and boulders are found filling the bottoms of canyons, as in Fig. 74, it is possible that water may be moving through these with a definite course and velocity.

Such conditions are found throughout the mountainous portion of the arid regions. The streams which flow through canyons or narrow gorges have, as a rule, filled up their beds. In ancient times the

streams cut their way downward into the solid rock to a depth considerably below the present stream channels. In modern geologic times these ancient channels have become filled to a depth of 10 feet, 20 feet, or even 100 feet or more. The material usually consists of large boulders, with occasional beds of gravel, sand, or even clay, left in protected nooks.

If this mass of material partly filling the canyons is dry, and a heavy rain occurs above, the water from the storm will flow down, saturating the surface, and gradually penetrating the lower layers until the spaces between the pebbles are filled. If the stream continues to flow for several hours, a considerable part of its volume may be taken in by the gravel, and the water may entirely disappear in the course of a mile or two, leaving the surface dry. A creek cannot continue to flow undiminished over a boulder bed until the latter is completely saturated with water. A little consideration shows that if water is withdrawn from the pervious material beneath the surface of a stream, it must be replenished, and that the surface discharge is reduced by the same amount.

The water saturating the gravels tends to move downward and forward under the influence of gravity, but its rate of flow, being diminished by friction and by adhesion to the surfaces of the grains, is far less than that of the water on the surface. While the latter may be travelling two

or three miles in an hour, the moisture underground, even in coarse gravels, probably does not pass over this distance in a week or a month. The rate of flow has not been determined, but a few experiments, made in different parts of the country, show that this rate is, under ordinary circumstances, extremely slow.

FIG. 74.—Dam across a rocky canyon, cutting off the underflow.

The accompanying illustration (Fig. 74) is intended to show how the underflow in narrow canyons has been utilized. An impervious dam, the top of which is shown in the figure as being above the surface, is built to bed rock, and the joints at the bottom and sides are made water-tight. Thus all of the water percolating down the gravel and boulder-filled channel, meeting this obstruction, is

retained, and, accumulating, may appear upon the surface. A pipe through this dam will draw off the water, but to receive the largest supply it must be placed near the bottom of the dam and not near the surface, as shown in the drawing. By means of such a submerged dam, small quantities of water are obtained. Where the channel is, however, of indefinite width, such dams are not practicable, since the percolating water will usually find its way around them.

The underflow in narrow or restricted channels, such as have been described above, has great importance in the development of irrigation and as a source of municipal supply. Many controversies have arisen concerning the relation which this bears to the surface stream. Some persons have contended that the taking of water by means of tunnels or other works built far beneath the surface does not perceptibly diminish the visible flow, claiming that the two streams are entirely distinct, being separated by impervious layers, or by a retardation of flow which behaves as an impervious layer.

One of the most interesting cases recently decided, bearing upon the character and ownership of the underflow, is that of the Los Angeles River of Southern California. The stream to which this name is applied appears upon the surface near the lower end of San Fernando Valley. The visible water gradually increases in volume as the valley

narrows, and in the gorge or canyon by which the stream makes its exit toward the ocean it attains a considerable and fairly constant volume. The river, as shown on Pl. XXXVII, *A*, appears to come from marshy ground, and might be said to have its origin here, but this water must have come primarily from the rainfall; and since the valley is relatively small, the amount which falls upon it would not be sufficient to maintain the river.

Throughout San Fernando Valley are many wells, some of them in gravel capable of yielding large quantities of water. Among the most important of these works for obtaining underground water are those of a company which purchased a large tract, tunnelled beneath the surface, and constructed infiltration galleries from which large and valuable amounts of water were obtained. The city of Los Angeles, owning the water in the river, claimed that this large development work, while a mile or more from the visible stream, was in effect taking water out of the river, and brought suit to restrain this unlawful diversion.

The water company claimed that under the common law they had an unquestionable right to take all of the water found beneath the surface of the land which they owned, since this water flows or percolates underground in undefined channels. It was, therefore, incumbent upon the city to demonstrate that the water in San Fernando Val-

A. WEIR MEASUREMENTS OF LOS ANGELES RIVER IN SAN FERNANDO VALLEY, CALIFORNIA.

B. RESULTS OF IRRIGATION FROM RIVERS OF SOUTHERN CALIFORNIA.

ley does move beneath the surface in defined channels, and that these feed the Los Angeles River as would be done by ordinary surface streams.

To make the situation clear, it will be necessary to explain the conditions a little more at length. To the north and east of San Fernando Valley is a large tributary watershed, coming from which are several streams, the most important of these being Big and Little Tejunga and Pacoima creeks. The mountains at the head waters of these streams are high and receive a considerable rainfall. A portion of this flows in the streams and continues downward to the edge of the San Fernando Valley, where it gradually disappears in the gravel and boulder channels or washes which extend out across the valley toward the points where Los Angeles River rises. These washes are usually dry on the surface, except in the rainy season, and thus the creeks named are not visibly connected with Los Angeles River.

It is claimed on behalf of the city of Los Angeles that the water progresses gradually beneath the surface along these washes, finally reappearing in the river to maintain the continuous discharge. The rival company's works were placed within these washes, and the assertion was made that, even though the water percolating through these gravels might ultimately reach the river, yet, since this did not flow in known and well-defined channels, there was no cause for action.

The court decided that the water travelling beneath the surface was a part of the Los Angeles River, and that these washes, well marked on the surface of the ground, indicated the presence of well-defined channels beneath the surface, these indications being confirmed by testimony based upon the depth of the water in wells and test pits. This was further supported by the analogy in the case of a pond filled with boulders. The San Fernando Valley might be regarded as a natural basin into which streams flowed from the hills, and out of which water was discharged at the lower end. The gradual filling of this pond with débris from the mountains would not completely displace the water, but it would continue to travel beneath the surface toward points of least resistance.

If the water at the outlet is all owned or appropriated, it would not be proper to permit diversions from the pond, even though this were filled with gravel in such a way as to obscure and break up the course of flow. It was held that "It makes no difference whether the onward flow is upon or below the surface, provided it is in a known and defined direction and in known and defined channels. The washes of the Tejungas and of the Pacoima are clearly cut and well defined from these streams to the Los Angeles River. In seasons of heavy rainfall these streams sometimes cut new surface channels through the sand, but for a long time they have maintained such channels

through substantially the same territory." "It is this subsurface flow that supports and sustains the flow of the Los Angeles River, and any diversion from it . . . amounts eventually to an equivalent abstraction of the same quantity directly from the river."

The fact that the testimony presented in this case has established the existence of well-defined channels underground should not be taken as implying that similar channels can be found wherever water occurs in considerable quantities beneath the surface. The topographic and geologic conditions must be thoroughly studied in order to discriminate between conditions where such channels do exist and those where the water is merely seeping or progressing slowly from point to point in broad, irregular deposits of gravel. In the latter it is usually impossible to demonstrate that there are any well-defined limits, since the gravels shade off into sands or clay, each mass of pervious material being perhaps isolated from all others, or connected by overlapping layers.

The effect of a well, or collecting gallery, in such a broad mass of gravel is not like that of similar works in a narrow channel with definite walls as shown in Fig. 74, since in the latter case all of the water travelling through the narrow channel may be within the sphere of influence of the well or tunnel, and may be abstracted. On the other hand, in the broad deposit the well may receive

water only from the immediate vicinity, the plane of saturation being depressed around the well, forming a conical slope toward the point from which water is pumped. Only the water within a relatively small distance from the well is thus reached, and the great body of water percolating through the broad gravelly layer is not affected.

To sum up and make more clear the difference which exists in behavior between different classes of underflow, it is desirable to present a mental picture of three conditions: First, an open body of water, such as a small pond. Water pumped anywhere from this immediately lowers the whole surface. The pond can be filled with large boulders and the same effect takes place. In the second condition the spaces between the boulders are filled with fine sand. Now water pumped from one side of the pond does not immediately lower the surface, and, if the material is sufficiently fine, a well sunk in it may be pumped almost dry without lowering the water around the edges of the pond, the slope of saturation extending from the bottom of the well steeply upward in all directions. There is a slow movement from all parts of the pond toward the well, but this may be so slow that very little water can be had. This is the case of percolation. The third condition obtains when fine sand fills the interstices of the boulders in the pond except along a narrow path or channel leading across the pond to the well. When the pump

is used the water will flow with considerable rapidity along this narrow boulder-filled path free from sand. This is, in effect, an underground stream with a definite channel which can be ascertained by test pits or boring. In this channel the behavior of the water is decidedly different from that of the other water which is slowly seeping in the surrounding, less pervious mass.

Like most other natural phenomena, the conditions which distinguish movement of water by seepage and by actual flow underground merge into each other, so that, while it is possible to say that here is an underground flow and there is merely an undefined seepage, yet the determination of the boundary line between the two is a matter of judgment. As yet no rule has been laid down, but the experiments and the decision of the court in the Los Angeles case have gone a long way toward clearing up this complicated subject.

ORDINARY WELLS.

Almost everywhere, even in the arid region, water can be had by digging wells at points near stream channels or along the foothills. Out in the broad valleys it may be necessary to go to a depth of from 100 to 300 feet or more before reaching moisture. Dug wells are the most common means of obtaining small amounts of water. Where the supply is ample, various devices for bringing the water to the surface have been employed, particu-

larly windmills, as described on page 265. The quantity of water is dependent upon certain geologic conditions, the sands and gravel usually being saturated and delivering water freely to any cavity in them.

In digging a well it is the custom to make the hole only large enough to permit one man to work in it. The soil penetrated must usually be held in place, masonry or brickwork being generally employed for this purpose, and occasionally wood. The latter, however, is liable to decay rapidly, impregnating the water and allowing the ground to cave in and fill the well. The hole is continued downward until water is struck, and then frequently the work ceases because of the difficulty of digging further.

To obtain a sufficient supply for irrigation, it is very important not to stop digging the well when the top of the water-bearing sands or gravel is reached, but to continue down into these. Sometimes this can be done by driving perforated pipe in the bottom of the well, thus penetrating layers of still coarser material and adding greatly to the capacity of the well. Sometimes these lower water horizons are under greater pressure than the gravels first struck, and water may rise through the pipe in the well up to and above the level of the bottom.

It is very important to provide a free passage for the water from the material in which it occurs.

This is sometimes done by driving galleries or tunnels from the bottom of the well out beneath the surface far enough to intersect coarser deposits, such as may have been laid down in ancient stream channels. These collecting galleries serve to bring small quantities of water toward a centre, where they can be had by pumping.

Work of this character is hardly practicable for ordinary farm or domestic supply, but has been successfully undertaken by towns and small cities in the West. With the development of population and the increase of the value of water, it is probable that investments of this character may be profitable for some forms of irrigation.

Water obtained mainly for irrigation is occasionally employed for other purposes, especially for household uses and for domestic animals. It is thus often important to protect it from pollution, particularly when obtained from shallow wells. It has long been recognized that the prevalence of typhoid and similar diseases in the country can often be traced to well waters contaminated by waste material from houses or stables. The same pervious layers of sand and gravel which drink in the rain water and deliver it to the well, also eagerly receive the drainage from outhouses and stables, and convey this also to the lowest point, where it may be pumped. It is, therefore, of the greatest importance to guard the purity of the water supply, first by locating wells at a suitable

distance from possible points of pollution, and next by constructing suitable lining or curbing to prevent surface drainage from being washed in. An efficient form of well curbing, shutting out surface drainage, is shown in Fig. 75.

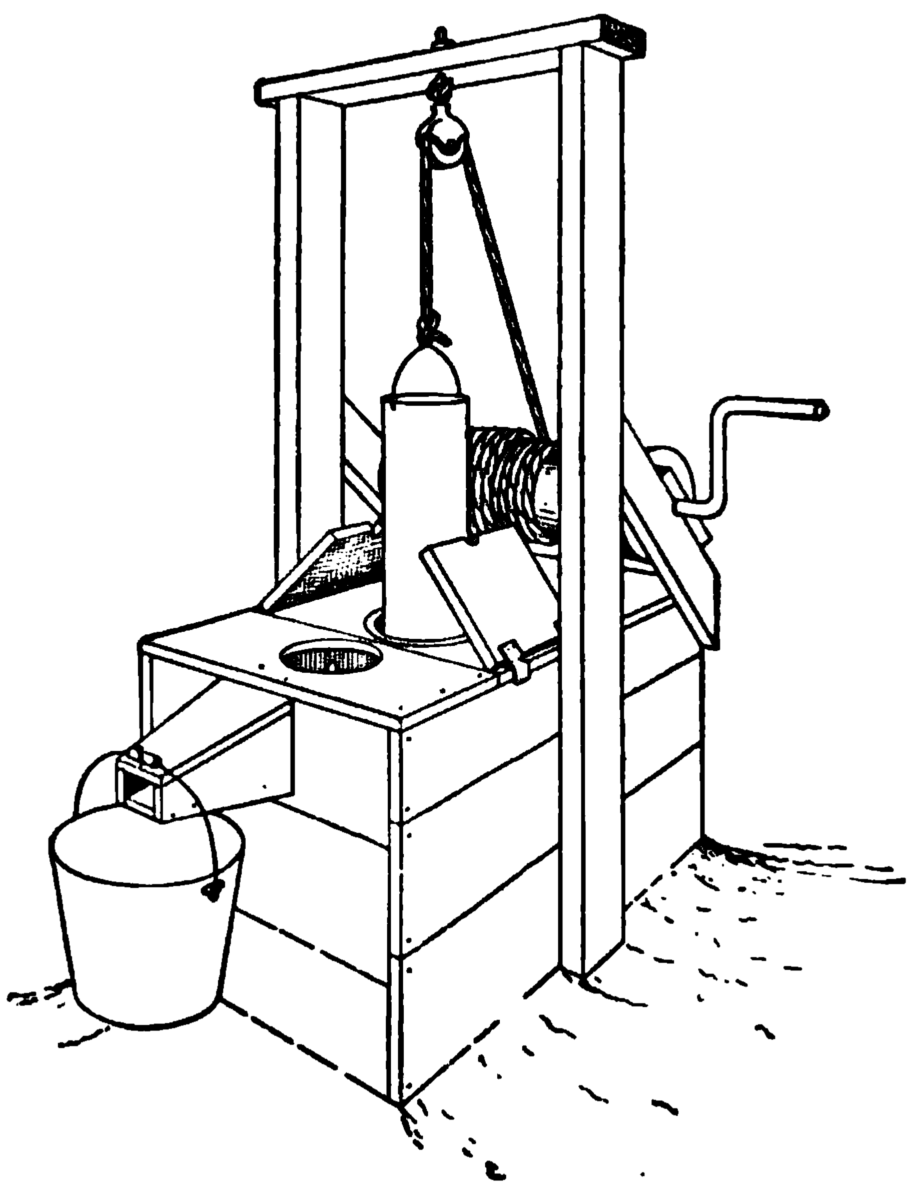


FIG. 75. — Ordinary well curbing and windlass.

Impure water has been known to penetrate through gravel to a distance of several hundred feet. In this course some of the injurious organic matter may be destroyed or consumed, but it is not safe to depend upon this action to any considerable extent. A simple test can often be applied by putting brine or crude petroleum at a point where waste material is deposited, and noting whether this affects the water in the well. For example, at a country home where typhoid fever occurred, it was believed that the well water was wholly undefiled; but on pouring a barrel of

crude oil into a cesspool 200 feet or more away from the well, within twenty-four hours the water in the well had become so impregnated with the oil that it could not be used. The water from the cesspool had undoubtedly been filtered in its long passage through sand and gravel, but had probably brought with it some harmful organic life.

When water is obtained from deeply buried gravels, the casing or lining of the well should be made perfectly water-tight from the top of the

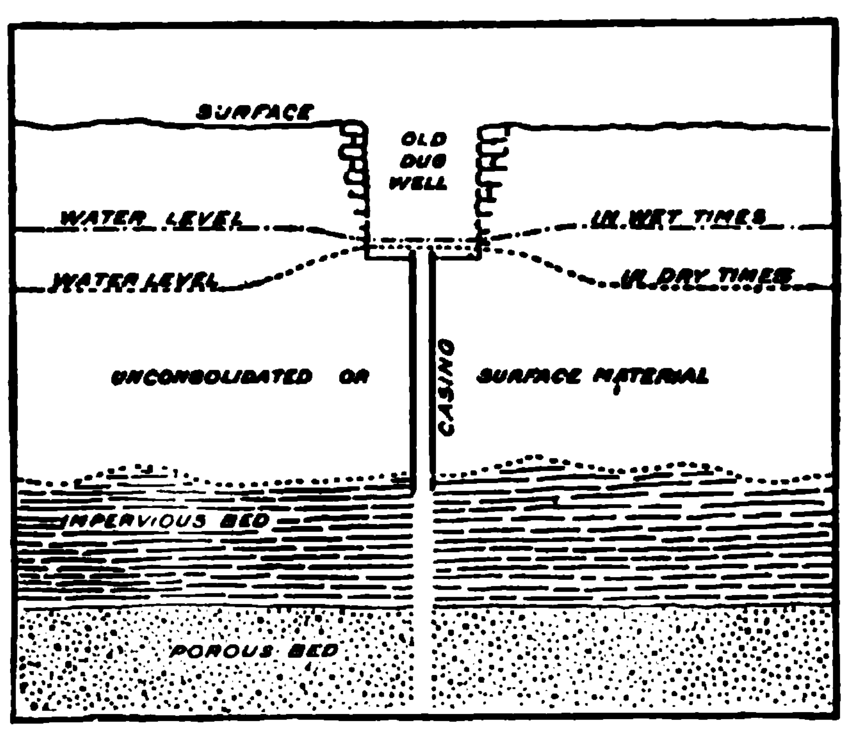


FIG. 76. — Diagram illustrating evils of insufficient casing.

water-bearing beds to a point slightly above the surface of the ground, in order to prevent contamination. In Fig. 76 is shown a somewhat common mistake in well-making. The owner first dug a well and secured a small supply of surface water. This not being sufficient, he put down a tube or

casing to an impervious bed, and in this drilled a hole until he reached a porous, water-bearing horizon. The water, being held down by the impervious cover, rose in the opening made, and filled the bottom of the well. In dry times a large part of the supply went to saturate the unconsolidated surface material in which the old well was dug, and in wet seasons the percolating rain water and surface washing mingled with the purer deep waters. For economy of water and for preserving the supply undefiled, the casing should have continued, as above stated, from the water-bearing bed to the surface.

ARTESIAN WELLS.

A great part of the water which occurs underground is found to be percolating slowly through the rocks and soils. When these are penetrated by a well, the water collects in this and assumes a level which represents the plane of saturation of the ground. Occasionally it happens that the pervious material, as sand or gravel, is overlain by an impervious bed, as shown in Fig. 76, and in a well dug through the latter into the gravel the water will rise to a height equal to the line of saturation in the surrounding country.

If the beds of alternating clay and gravel are inclined, or tilted by earth movement, water will follow down under the clay or impervious shale, gradually acquiring greater and greater pressure. The

A. ARTESIAN WELL IN ARIZONA.

B. ARTESIAN WELL IN KANSAS.

impervious roof holds the water down until pierced by a well. The term "artesian" is applied to wells in which the water actually overflows the surface of the ground, as shown on Pl. XXXVIII. There is no commonly accepted designation to cover the case of wells in which the water rises but does not overflow, this being characteristic to a greater or less extent of nearly all artificial openings in the ground. The term "negative" artesian wells has sometimes been applied in this connection, but in its original sense it was used to cover the condition where water is held up by an impervious layer, and when the latter is penetrated the water flows downward to a lower level of permeable rock. Several swampy areas in southern Georgia have thus been drained by boring deep holes in the lower portions. The surface water has escaped down these holes to unknown depths.

The accompanying figure (77) illustrates one of the conditions of artesian structure. One side of a basin is represented, the porous beds of sand or

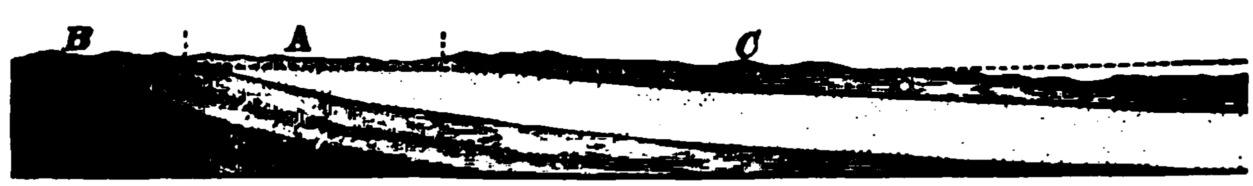


FIG. 77. — Section of one side of an artesian basin.

clay marked *A* outcropping as a rolling upland; below and above this are impervious beds marked *B* and *C*.

The next figure illustrates the conditions where the coarse material *A* has not been curved in a

basin, but is sloping in one direction, such as might occur where sand and gravel have been deposited on a sloping sea-coast and after subsidence have been covered with clay. The pervious bed *A* receives water from rainfall on its exposed edges. It slopes

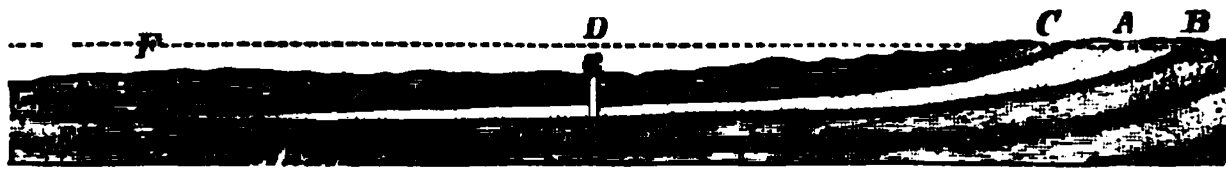


FIG. 78.—Section illustrating the thinning out of a porous water-bearing bed, *A*, enclosed between impervious beds, *B* and *C*, thus furnishing the necessary conditions for an artesian well, *D*.

gently inward and, lying on the impervious layer *B*, is covered by the clay or shale *C*. A well at *D* penetrating these will overflow, and if the pipe were continued upward would rise to the level of the line *CF*, this being the plane of saturation of the area which receives the water from rainfall.

Artesian conditions occur in nearly every state, but they do not extend over any considerable portion of the country, except on the Great Plains and in the valley of California. Wherever they do occur the water has considerable value on account of the convenience incident to its rising above the surface. In some places, as in the James River Valley of South Dakota, the pressure is 100 pounds or more to the square inch, throwing the water to considerable heights and enabling the wells to be used as sources of power. For this purpose a small stream is directed against an impulse wheel, or connection is made with a reciprocating water

OUTFIT FOR DRILLING DEEP ARTESIAN WELLS.

engine, as at Aberdeen, South Dakota, where the sewage of the city is pumped automatically by machinery of this character. The city supply is obtained from two or three deep wells, the pressure being sufficient to throw streams through fire hose over the highest buildings, and, as just noted, the surplus water is disposed of by the force from still another well directed into suitable engines.

Pl. XXXIX shows the derrick and the most conspicuous portion of the machinery for drilling a deep or artesian well. The skeleton tower or derrick is 72 feet high, being sufficiently tall to support, from a pulley at the top, the long slender steel drilling tools which are suspended from a stout cable. With the arrangement shown, wells 1000 to 3000 feet in depth are drilled.

Occasionally the water from these deep wells is saline or brackish, and thus has little value, unless the brine is so strong as to be useful in the manufacture of salt. Water slightly saline to the taste can be used in irrigation if care is taken in cultivation to prevent the accumulation of earthy salts.

By the thorough study of the geologic structure and of the condition of the rocks as regards permeability and slope, it is possible to prepare maps showing the underground condition with reference to flowing wells, and to outline the areas where water will rise to or above the surface, and also to indicate the depth of the water-bearing rocks. Such maps have been prepared for a small portion

of the country. By means of them the farmer or citizen can ascertain whether it is probable that water can be had, the depth, and the character of the rocks to be penetrated, thus making it possible for him to estimate the expense of obtaining water in this way.

The amount of water to be had from deep wells is governed largely by the diameter of the well,

FIG. 79.—Geologic section from the Black Hills east across South Dakota (western half).

but more by the structure and thickness of the water-bearing rocks and the head or pressure under which the water occurs. From relatively dense rocks a slight head or pressure of water will force only a feeble stream, but from thick layers of open gravel or sand-rock large volumes are delivered, the quantity being limited by the size of the pipe of the well. This is usually from 2 to nearly 6 inches in diameter, the ordinary wells averaging

about 4 inches. It is not to be supposed, however, that by increasing the diameter a correspondingly large amount of water will be obtained. It frequently occurs that a 4-inch pipe will deliver all of the water that can reach this point, and enlarging the diameter of the well to 4 feet will not increase the flow.

The source of the water coming to artesian wells may be at a distance of several miles or several hundred miles. The large amount obtainable in eastern South Dakota probably has travelled underground from the eastern front of the Rocky Mountains or from the Black Hills, distances of from 200 to 400

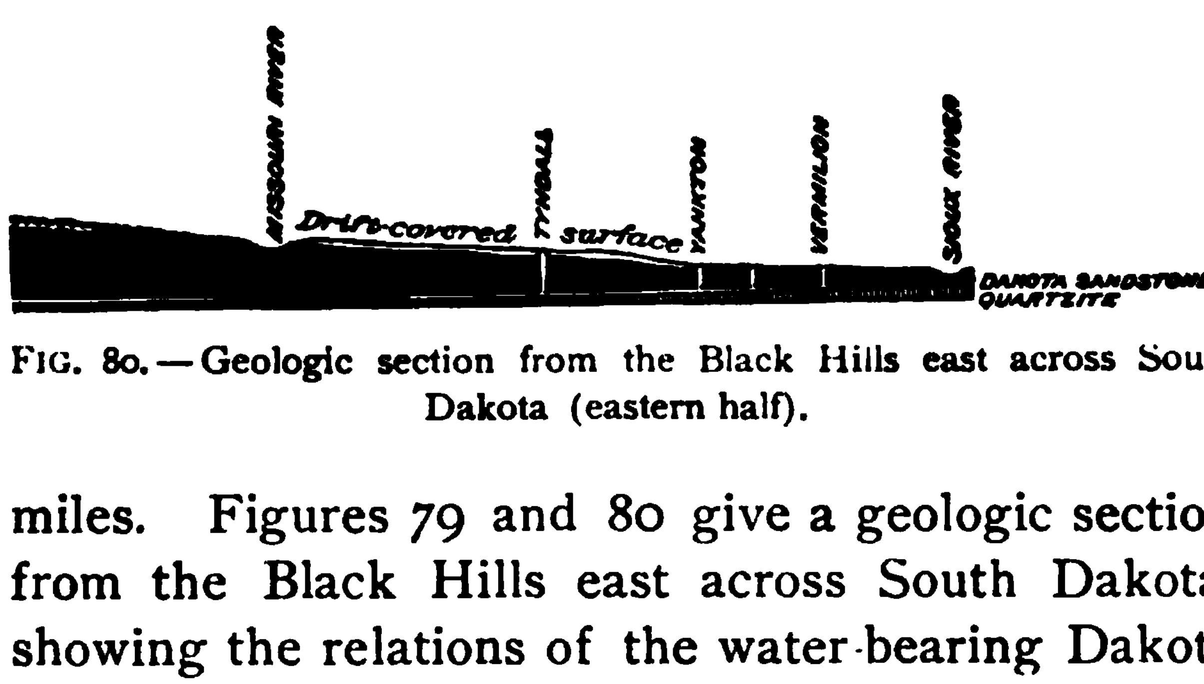


FIG. 80.—Geologic section from the Black Hills east across South Dakota (eastern half).

miles. Figures 79 and 80 give a geologic section from the Black Hills east across South Dakota, showing the relations of the water-bearing Dakota sandstone to the overlying impervious shales and to the artesian wells in eastern South Dakota receiving their supply from the sandstone. A view of one of these wells is shown in Pl. XL. This is at Woonsocket, South Dakota, a 3-inch stream being thrown to a height of 97 feet.

The area of rock thus saturated may aggregate many hundred square miles, and the volume stored underground is thus very large. On the other hand, an artesian basin may be small, the rocks outcropping in the near vicinity of the well and receiving only a small supply from the annual rainfall. One or two wells drilled into a small basin do not perceptibly diminish the pressure or the flow; but as the number is increased the stored water is drawn upon more rapidly than it can be replenished, and the pressure greatly diminishes, until the wells no longer flow unless some of them are stopped. A condition of this kind has occurred in the artesian basin in the vicinity of Denver, Colorado. All of the wells within or near the city have ceased flowing, and water is obtained from them by pumping. Out in the country, in a more remote portion of the basin, some of the wells still flow. This general diminution of pressure has not been noticed in the larger artesian basins, such as those in the San Joaquin Valley of California, the Moxee Valley of Washington, the James River Valley of South Dakota, and the San Luis Valley of Colorado.

Some artesian wells have decreased or stopped flowing, not from lack of water, but because of mechanical defects in their construction. Fine sand has accumulated, stopping up the well, or the tubing or casing has rusted away, permitting the water to escape into pervious rocks below

WELL AT WOONSOCKET, SOUTH DAKOTA, THROWING A 3-INCH STREAM TO A HEIGHT OF 97 FEET.

ground. In some localities where wells were abandoned because the water did not rise to the surface or the flow was unsatisfactory the casings of the wells have been drawn for use elsewhere. The water has continued to rise from the bottom of the well and to escape into the higher porous strata, permitting a continual outflow from the artesian water-bearing rocks. Several artesian basins have been greatly weakened or even destroyed by such treatment. In the construction of artesian wells it is highly important to provide suitable casing to prevent the wells leaking into the dry rocks, and, in short, every precaution should be taken to prevent waste of water or destruction of other wells through careless management of one or two.

The amount of water delivered by an artesian well varies from a few gallons a minute to as high as 5 cubic feet per second or even more. Wells flowing 1 cubic foot per second have great value in irrigation, as by storing this water 100 or 160 acres can be watered. The advantages of water obtained in this way are very great, as the owner of the well is independent and can use his water when and where he wishes, while the irrigator depending upon a ditch system cannot. Artesian well water is also free from seeds of weeds and is usually somewhat warmer than the ground; thus it does not chill the plants, as is sometimes the case with water from mountain streams.

CHAPTER VIII.

PUMPING WATER.

It has previously been stated that the greater portion of water used in irrigation is diverted by gravity from flowing streams. While this is true as regards bulk of water, as regards value it may be said that some of the most important sources of supply are utilized through pumping. In ancient times, especially in Egypt and India, where labor had little value and the conditions for divert-

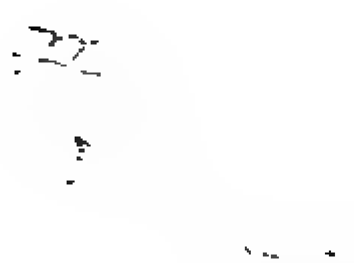


FIG. 81. — The doon, or tilting trough.

ing water by gravity were not favorable, pumping by hand or by animal power was largely practised.

The accompanying illustration shows a crude device, a tilting trough known as a doon. This is pivoted near its centre, and is counterbalanced by rock in such way that one end of the doon can be pressed into the water, the weight of the rock then lifting this end, elevating it sufficiently to throw the water into a ditch.

PUMPING BY HAND OR ANIMAL POWER.

Another view (Fig. 82) is of a series of well-sweeps, or shadoofs, as still used in Egypt, this

FIG 82.—Series of shadoofs as used in Egypt.

device being also employed in modified forms in many countries. By means of it water is raised

from 5 to 10 feet or more. As shown in the view, a series of shadoofs are arranged, to avoid greater lifts, the water being raised first to one level and then to the next, and so on until the top of the bank is reached. With these well-sweeps the workman uses his weight to depress the bucket into the water, whence it is lifted largely by the counterweight, the bucket being swung over and emptied when it reaches the proper level.

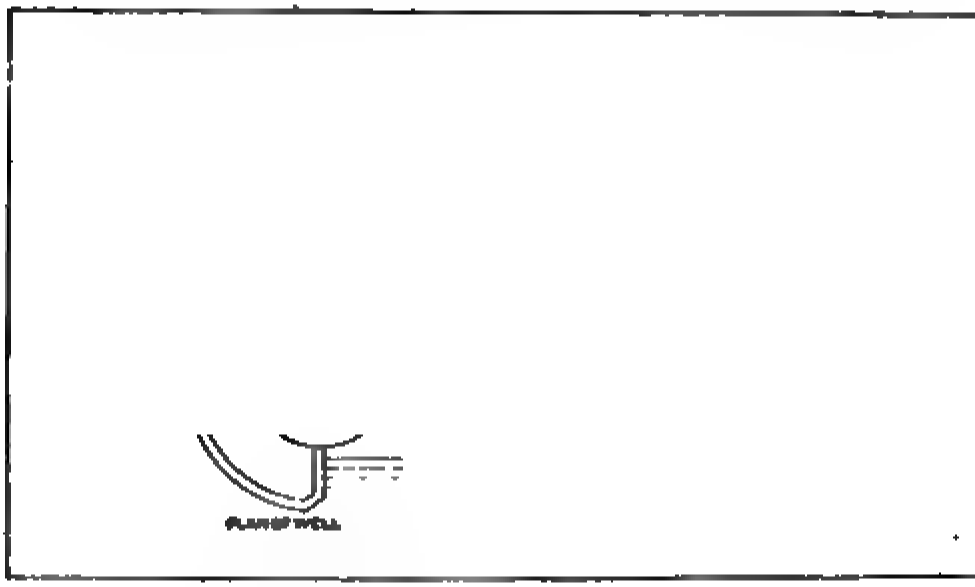


FIG. 83.— A mot, operated by oxen.

Animal power is used in many forms, either in directly pulling up a bucket or skin full of water, as shown in Fig. 83, or in operating some form of pump. The device shown is known as a mot, and consists of a rope passing over a pulley and down into a well, to the lower end there being attached a receptacle for the water. The animals, walking away from the well, usually down an incline, draw

the bucket to the top, where it is emptied. The animals then walk backward to the well and repeat the operation.

In modern times these devices have been improved upon, although some of them are still utilized in crude form by pioneers in the arid region. The well-sweep has in general been replaced by the windlass, which raises water in a

FIG. 84. — Horse-power for lifting water.

bucket, as shown in Fig. 75. With ordinary farm wells of this kind irrigation is impracticable, other than the watering of a few trees or plats of vegetables; but the beginnings of irrigation on many a farm in the subhumid region may be traced to successful experiments with water raised in this laborious manner.

The next step in pumping water under pioneer conditions has frequently been the utilization of horse-power. The accompanying figure (84) shows a simple device, by which a horse walking in a circle causes a series of buckets to be lifted from the well, drawing up water sufficient for several acres. The possibility of irrigation in this way is limited largely by the depth to water and the number of animals available.

USE OF WATER-WHEELS.

The force of flowing water has been frequently employed to bring water up to the level of the irrigable land. The bucket wheel has been utilized from the earliest historical times to the pres-

FIG. 85.—Current wheel lifting water.

ent. This consists of a paddle-wheel with a series of buckets arranged around the rim in such form that when the wheel revolves by the force of the current, the buckets are filled, raised to the top, and emptied into a trough, which conducts the water into the irrigating ditches. Wheels of this kind are to be seen along most of the swift-flowing rivers of the West, as shown in Pl. XLI, some of them being as much as 30 feet in diameter.

Where there is sufficient fall in a stream to develop water-power, this can be used by means of various standard forms of water-wheels, such as the turbine, these in turn operating pumping engines. Such devices are employed occasionally to obviate the necessity of building expensive lines of canal, the power of a stream being used to pump the water to the top of a high bank, which otherwise could be surmounted only by many miles of canal, with costly flumes and tunnels.

With small amounts of water descending precipitously and giving a head of several hundred feet, various forms of impulse water-wheel, as shown by Fig. 86, have been employed. This device develops great power for a small amount of water, and can be used to actuate various forms of pump to bring water, either from underground or from surface sources, up to the land which it is desired to moisten.

The increase of irrigated areas in many parts of the United States is being brought about by the

facilities for pumping afforded by the development of water-powers and the transmission of the energy by electrical means. The regulation of the stream by storage reservoirs for the purpose of supplying water to the fields frequently creates conditions favorable for producing power for operating water-

FIG. 86.—Impulse water-wheel.

wheels of one kind or another. These points are, however, usually remote from centres of population and possible markets for the power, and the works built here would be valueless were it not for electrical transmission. There is an awakening of agricultural and industrial activity following each improvement in electrical transmission.

Up to about 1890 there was a rapid decrease in the relative importance of water-powers in the United States; but this has been checked by the

CURRENT WHEELS LIFTING WATER.

practical application of methods of conveying the power by wire, some of these being on a large scale. In this respect the West has led in certain features, largely because of the great expense of fuel there and the fact that development has not been hampered by vested rights to the use of the rivers. Throughout the East, in New England especially, water-powers have been utilized to a notable extent, and the vested rights which have resulted have served to retard changes or improvements. The costly structures and machinery already erected have not been adaptable to new requirements, and often it has been found cheaper to abandon important powers rather than incur the expense of extinguishing various claims and remodelling existing factories.

The advantages of water-power over other sources of energy are, however, so decided that it is apparent that, with improved methods of operation, important falls or rapids will soon be utilized. As a rule it is cheaper than steam-power, for the water costs nothing and the expense of maintenance of hydraulic machinery and of superintendence is small. The annual cost of power consists almost entirely of interest charges on the original investment.

In the United States there are many large rivers and innumerable small creeks descending with rapid fall from the mountains in regions where fuel is expensive. There water-power must always

have great importance in industrial development. By combining the power transmitted from a number of small streams distributed over one or more counties, it is possible to bring together at the seaboard or at centres of population an amount of power comparable to that had from some of the great rivers.

In past decades water-power has been employed only in the immediate neighborhood of a natural fall; and where distributed to different manufacturing establishments, this has been rendered possible by dividing the water and allowing it to flow to the various water-wheels located in the factory buildings. This has necessitated the crowding of the buildings together, or a large expenditure for conveying the water to a considerable distance. In New England the permanent works for procuring and dividing this water have been among the most expensive in the world, and corporations have been formed for the purpose of controlling a large river and furnishing the water to manufacturing establishments, instead of generating power and then selling it.

An example of this system of dividing water is on the Merrimac River at Lowell and Lawrence, Massachusetts. At the latter place the Essex Company has built an expensive masonry dam, giving a fall of 28 feet and obtaining 10,000 horsepower during working hours. This dam is 900 feet long and 32 feet in height, the cost being esti-

mated as $250,000. From each end of this canals extend down-stream and mills are located along these canals between them and the river. The canal on the north side is a trifle over a mile in length and 100 feet in width at the upper end, and cost approximately the same amount as the dam. The canal on the south side is about 2000 feet long and 60 feet wide, and cost about $150,000. Water is leased or sold to the mills at a certain fixed rate, the Essex Company maintaining the dam and canals and delivering the water at the penstocks of the mills, from which it flows through the wheels and is discharged back into the river. The condition here is typical of that at many other points in New England, and illustrates the form of development where water is distributed to many manufacturing establishments.

In marked contrast to the above conditions are those growing out of the ability to divide the power and transmit it electrically to places distant 100 miles or more. Here it is no longer necessary to crowd the manufacturing establishments together, but they may be scattered widely over the country, at points where material and labor can be had to best advantage. The power of the falling water can be transformed into electrical energy in a single establishment, from which wires radiate in all directions; or if the water-power is diffused in a number of small streams, each of little importance alone, several plants can be erected and the power

concentrated by lines leading to one large factory. This facility for transmitting power has revolutionized many industries, and attention is now given to small water-powers which in times past have been neglected or abandoned as useless.

A third step in progress is made where many sources of power are brought together into one system, and this branches out to localities where power is needed. Each water-power becomes a feeder to a main trunk line, and this line divides to numerous establishments. Such is the condition in Southern California, where a number of generating stations have been erected in various canyons, and the electric wires, converging toward Los Angeles, make possible numerous industries in the vicinity of the city and drive many small irrigating pumps. The arrangement is carried to an extent such that a manufacturing establishment, like a cement mill, may take power during the daytime, when it is in least demand for light, and later return an equivalent by turning in the energy developed by its steam engines.

All of these economies resulting from the utilization of forces otherwise lost have interest in a consideration of the extent to which the arid lands can be redeemed by irrigation, as they are part of the general system of turning to beneficial use the resources now going to waste. Cheap power means ability to pump water, and water supply in turn makes possible an extension of

irrigation, and this is the principal step toward more homes and a settled population.

WINDMILLS.

The most important and widely distributed source of power for pumping water is wind. Over the broad valleys and plains of the arid region the wind blows without ceasing for days and weeks, carrying away the dry leaves, and even at times sweeping up the loose soil. In many localities there are, at depths of 20 to 50 feet or more beneath the surface, pervious beds of sand or gravel filled with waters by the infiltration of rainfall or by percolation from stream channels.

It is a comparatively simple and inexpensive operation to sink a well into this water and erect a windmill, attaching this to a suitable pump. The machinery, once provided, is operated day and night by the ever present wind, bringing to the surface a small but continuous supply of water. This small stream, if turned out on the soil, would flow a short distance and then disappear into the thirsty ground, so that irrigation directly from a windmill is usually impracticable.

To overcome this difficulty it has been found necessary to provide small storage reservoirs or tanks, built of earth, wood, or iron, to hold the water until it has accumulated to a volume sufficient to permit a stream of considerable size being taken out for irrigation. Such a stream flowing

rapidly over the surface will extend to a distance and cover an area which would seem impossible with the small flow delivered by the pump.

The windmills employed in irrigation are of all kinds, from the highest type of the machinist's art down to the crude home-made devices. The latter are not to be despised, as many of them are highly effective, and at least they have enabled settlers to procure a small amount of water and to obtain a foothold upon the soil, by which ultimately they may be able to obtain funds to procure better implements.

The accompanying Pl. XLII shows a number of these home-made devices, some of them being in the form of turbine wheels, and others, known as the "Jumbo," consisting of horizontal paddle-wheels so arranged that the wind sweeping over the top of the structure strikes the exposed sails and causes the wheel to revolve. On each end of the axis of this wheel are attached the pump rods, which move up and down as the wheel revolves.

Such home-made mills are, of course, of low efficiency as regards the proportion of power utilized. But since the force of the wind is practically limitless, the mechanical efficiency of the device is of little consequence, provided it does the work required. The material for these mills costs from $5 to $20. They are easily repaired and will serve for many years. Such machines are, of course, not comparable, as far as workman-

A. JUMBO TYPE OF HOME-MADE WINDMILLS.

B. BATTLE-AXE TYPE OF HOME-MADE WINDMILLS.

ship is concerned, with those made by manufacturers of implements; but the cheapness of the device has enabled many a settler, discouraged in the attempt to farm without irrigation, to obtain a water supply and successfully raise a vegetable garden sufficient to support his family, and also to put up a small amount of forage for his cattle.

In building these mills pieces of old mowing machines or reapers have been used for axles, bearings, and connections. The sails have been made of pieces of dry-goods boxes and old lumber around the farm, and the whole machinery stiffened and held in place by bale wire or other waste material found in quantities around the houses of men who have attempted to make a living upon the plains. Thousands of settlers have pushed westward from the humid into the subhumid portions bordering the arid region, and in years of abundant rainfall have been able to raise one or two crops. With the changing cycles of moisture, these regions becoming dry, the pioneers have lost their crops year after year, and have been compelled by starvation either to leave the country or to change their methods of farming. Under these circumstances, discouraged, without capital, some of the more ingenious and persistent settlers have been able to dig wells, build windmills, and irrigate a small patch of ground, and, gradually adapting their methods to the climate, have improved upon their conditions and made comfortable and perma-

nent homes. The crude windmill has then given way to the shop-made mill, Pl. XLIII, with its neater appearance and greater efficiency. The contrasting conditions have been illustrated on Pls. I, II, and III.

The accompanying figure (87) shows two of these mills placed on opposite sides of a small earth reservoir, into which water is being pumped

FIG. 87. — Windmill pumping into earth reservoir.

for irrigation. Sometimes as many as half a dozen mills are placed around a tank of this kind, a number of small mills being found better than one or two large ones. When the diameter of the wheel is increased much above 10 or 12 feet, the strength is considerably diminished and liability to injury during storm is greatly increased. Small, rapid-running mills, 8 to 12 feet in diameter, have, therefore, been found most economical. If one is injured, the others will usually continue pumping.

The disadvantage of windmills, as a class, is that most of them are constructed to operate only in moderate winds. The very lightest breezes often pass by without starting the wheel in motion. As the strength of the wind increases, the wheel begins to revolve, reaching greater and greater efficiency until the velocity is about 8 or 10 miles an hour. At greater speeds the mills are usually so constructed that they begin to turn out of the wind in order to protect themselves, and thus the efficiency begins to drop off rapidly as the wind becomes more and more powerful. When it approaches a gale the mill stops completely, and thus, at the time when with sufficiently strong construction the greatest amount of water could be pumped, the machine is standing idle.

One of the important inventions yet to be made is a simple, strong windmill which will continue in operation throughout a heavy wind. Many mechanicians have tried their hand at something of this kind, but have not yet succeeded in producing a commercial article. The suggestion has been made that pumping by wind may reach its highest efficiency through the use of compressed air, the windmill operating some form of simple air compressor, from which a pipe will lead down into a well, and through it water be forced out by means of what is known as an air lift. If such a device is practicable the windmills can be located on the highest point of the farm, and the com-

pressed air be carried down to the lower-lying wells.

PUMPING BY STEAM AND GASOLENE.

Where the conditions are favorable, water is raised for irrigation by ordinary steam pumps or by machinery actuated by gas, gasolene, or hot-air engines. In the vicinity of cities and towns having waterworks, lawns and small gardens are thus irrigated by hydrant water, the area of each being small, but the aggregate amounting to many thousand acres.

Steam pumps have been installed for irrigation by some market gardeners and by farmers who have engines for threshing and other farm uses. Various forms of centrifugal pumps are generally employed, these being connected by means of a belt to the ordinary engines. Water is thus raised usually not to exceed 20 feet in height.

Gasolene engines are being largely employed where coal and wood for fuel are expensive, and where the depth to water is not very great, say from 15 to 30 feet. The forms of machinery are very diverse, and there are on the market a considerable number of engines, pumps, and mechanical devices, many of which have been successfully used, while others are still in experimental stages.

The cost of pumping water by engines driven by steam, or by similar machinery, differs with the cost of fuel, the amount of labor involved, and the

WINDMILL PUMPING INTO SOD-LINED RESERVOIR.

depreciation of the plant. It is, as a rule, considerably higher than the amount yearly paid for the maintenance of canals and ditches in the arid region, or the amount paid annually to a canal company for delivering water. It is rarely below $2 per acre irrigated, and, from this as a minimum, may rise to $5 or even $10 an acre. This method of obtaining water will not be profitably employed for general crops, except those, such as rice, where the conditions are such that the industry is impossible without resorting to this means of obtaining water.

In humid and subhumid regions pumping plants are at present more widely used than canals taking water from rivers, because they can be erected by an individual upon his own land without any complications as regards riparian rights or control of the waters. Being compact and under cover, the machinery can be kept from deterioration and in readiness for use in times of emergency, supplementing the deficient rainfall. Where windmills have been utilized and it has been found by experience that the wind is unreliable, the irrigators frequently resort to gasolene engines to keep the pumps running during calm days.

CHAPTER IX.

ADVANTAGES AND DISADVANTAGES OF IRRIGATION.

THE advantages of irrigation and the benefits resulting are to be inferred from what has been given in the preceding pages. In brief, it may be said that these consist in the ability to supply water at the right time and in proper quantities to the growing plants, resulting in the largest and best development of these and facilitating a close tilling of the soil, a rapid succession of crops where the temperature is favorable, intensive farming, and a dense rural population, with all of the accompanying benefits of rapid communication, modern improvements, and social intercourse. As one of the advantages also may be enumerated the ability to put to use, by sewage irrigation, the waste matter from organic life, bringing together and making of value the sandy places and the substances which otherwise become nuisances.

There is no gain without some small loss, and it must be recognized that there are some disadvantages connected with irrigation. Labor and vigilance are necessitated in applying water to the fields. The proper supply may not be available

when needed. Marshy conditions may result from excessive use of water by neighbors or from unavoidable causes, and, worse than all, the artificial application of water to the soil may bring to the surface such a quantity of earthy salts, known as alkali, that the land, otherwise fertile, is ruined. In humid climates also, after a heavy or clayey soil has been irrigated, a sudden shower may occur, drenching the fields and injuring the crops. Under proper conditions, however, such as those realized in parts of the country where water is intelligently applied to the soil and the tilling is thoroughly done, the most remunerative and beneficial returns are had from the irrigated lands.

If, for any cause, the proper amount of water cannot be had and applied as needed, irrigation fails of being complete, and disasters ensue detrimental to the further spread of this method of agriculture. Incomplete irrigation, like an unfinished building or any other project stopped halfway, is always discouraging. In so far, therefore, as irrigation may be chronically liable to lack of completeness through a deficient water supply, it becomes disappointing.

A serious source of annoyance is that occasionally experienced by scarcity of water. While many of the irrigators enjoy a perennially abundant supply, there are others in nearly every community whose farming operations are rendered precarious because in one year or another they

suffer from a shortage of water. The disaster resulting depends largely upon the character of the crops planted; some kinds may be able to survive the drought and yield a small return, while others may be a total loss.

The higher the development of an industry, the greater the opportunities for failure and the wider becomes the effect of disaster. Irrigation may be considered as the highest type of agriculture, and, under favorable circumstances, largest results may be expected; but, as in every other highly specialized industry, not every man makes a success.

If one hundred men should be placed upon new land in a humid climate, and the same number on irrigated farms in the arid region, it is probable that at the end of five years there would be a greater proportion of successful farmers among those on the land depending upon rainfall. As time went on, however, and the art of irrigation became better understood, the returns from the irrigated lands would far outstrip those from the humid. With ability to apply water to the dry fields at the right time, the regularity of the crop is insured, and farming operations can be conducted with a certainty unknown in humid climates.

Small farms are characteristic of successful irrigation development. Throughout Utah, for example, the average size of an irrigated area is less than thirty acres. By means of this, a family is supported in comfort and there is a gradual in-

THE DESERT RECLAIMED.

crease in wealth. The advantages of ownership in small tracts can be seen at a glance in the well-tilled fields and the general appearance of suburban activity and prosperity. There is none of the loneliness and isolation, so depressing where farmers' families live a mile from one another and rarely see any one except a few acquaintances and have little means of keeping in touch with the activities of the outside world. The cultivation of small tracts also necessitates more or less diversified farming: fruit trees and vines are raised, and when one crop is removed another may be planted if the season is not too severe. A few cattle and sheep are kept upon the neighboring open range, and there is continued occupation throughout the year for all able-bodied members of the family in caring for the fruits, the gardens, or the animals. This is in marked contrast to the great wheat farms, where the work is concentrated during a few months and the prosperity of the family is dependent upon a single crop. There is developed in the irrigated regions a better class of citizens, with broader experience and wider interests.

SEWAGE IRRIGATION.

Irrigation affords not only a method of stimulating plant development, but it has been found to be advantageous in both humid and arid climates in furnishing a means of disposal of various waste products resulting from human and animal activi-

ties, making these of use instead of allowing them to become sources of annoyance. One of the most convenient ways of getting rid of deleterious substances has been to throw them into running water, or to use flowing water as a means of convenience for taking away organic matter which otherwise, by accumulation and decay, would be injurious to health. From the earliest times creeks and rivers have been regarded as the natural means of deliverance from nuisances. With the introduction of waterworks and systems of sewerage, we have, in effect, diverted the streams to our doors and made them carry away our refuse.

At the same time these streams, or portions of them, serve as sources of water supply, and it not infrequently happens that a river which is in effect an open sewer for a considerable population is used at lower points to furnish drinking water. This condition, when plainly stated, is highly repugnant, but nevertheless exists throughout the United States. The city of Washington, for example, has for many years taken water directly from the Potomac River, which receives near its head waters the drainage from coal mines, the refuse from manufactories, and along its course the sewage from towns and cities of considerable size. Although a large portion of the organic matter in the water may be destroyed by sunlight and exposure to the air, yet, with the known great vitality of the lower forms of life, it is highly probable

that the germs or bacilli of typhoid and related filth diseases travel for many days without complete destruction.

The existence of this condition has led to careful study of the question whether a better disposal of sewage cannot be made. Although sources of annoyance and even danger to public health, yet these waste products have some value as fertilizers. If, instead of defiling the rivers, the sewage can be put upon agricultural land, two objects will be accomplished — the preservation of the purity of rivers, and the consequent great gain to health and to various industries dependent upon pure water, and the increase in fertility of sterile soil.

The conditions in Europe in regard to pollution of streams have become far worse than in the United States, because of the greater density of population. Elaborate experiments have been made to demonstrate the practicability of using sewage in the irrigation of farming land; and in the vicinity of Paris, Berlin, and a number of other cities large tracts are being cultivated by its use. The chief difficulty arises from the fact that there is a certain amount of sewage to be disposed of, summer and winter, in the crop season and out of it, and this quantity is often greatest during storms or at times when plants do not need additional moisture. It is, therefore, necessary to provide large areas of land, and to regulate the application of water to these more with reference to getting

rid of the sewage than with thought of the actual need of the plants.

In the handling of a large quantity of water a very pervious or sandy soil has been found best, since this will take up a large amount of sewage and retain the organic matter where the roots of the plants can reach it, acting to a certain degree as a filter, and delivering clear and harmless water to the drains beneath the surface. The plants, during the season of growth, utilize the organic matter, and by the aid of the nitrifying organisms convert it into food for animals or change it to innoxious substances.

The accompanying illustration (Pl. XLV) gives a view of a field of young corn being irrigated by sewage at Plainfield, New Jersey. The sewage is seen standing in furrows between the rows. The water soaks away rapidly, and after the ground has become partly dry more sewage is let in, this being repeated as rapidly as possible without injury to the growing plants. In this way a rank growth is obtained. On Pl. XLVI, *A*, is shown a view of the sewage-disposal works at Phœnix, Arizona. Here the waste water from the city is carried to a tract of low, sandy ground, portions of which are rented to Chinese gardeners, who produce wonderful crops.

The view on the same plate, *B*, is of a similarly irrigated farm in England, being situated, as shown by the picture, in a densely populated region. If

SEWAGE IRRIGATION AT PLAINFIELD, NEW JERSEY.

properly conducted, there should be no odor from such a farm, and its existence need not be a cause of offence. If neglected, however, or improperly managed, the sewage may become extremely unpleasant.

Sewage irrigation has been found profitable on sandy soils, even in humid climates, where the rain furnishes ordinarily an ample supply of water for plants. The increased yield due to the constant moistening of the soil and the addition of fertilizing material more than repays the additional labor and expense of applying the sewage. In the arid regions, where water has greatest value, it would seem self-evident that sewage irrigation must ultimately be carried on to such an extent that none of this material will be wasted.

This method of disposing of sewage may be considered as a form of slow, intermittent filtration, in which the top of the filter is used for growing crops. After each watering the ground should be cultivated, in order to stir the sewage into the soil and bring the organic matter in contact with particles of earth. The frequent wetting of the ground, followed by thorough cultivation and the sinking away of the water, allowing the air to enter, favors the growth of the nitrifying organisms which convert the waste matter into plant food, this being taken away by the crops as rapidly as it can be utilized. There exists in some localities a strong prejudice against the use of vegetables grown by

sewage irrigation. Experience has shown, however, that with proper care in applying the sewage, to keep it away from immediate contact with the plants, and in washing the vegetables when used in cooking, there is no more danger to health than is likely to occur in the use of ordinary fertilizers, such as stable manure. In fact, the precautions

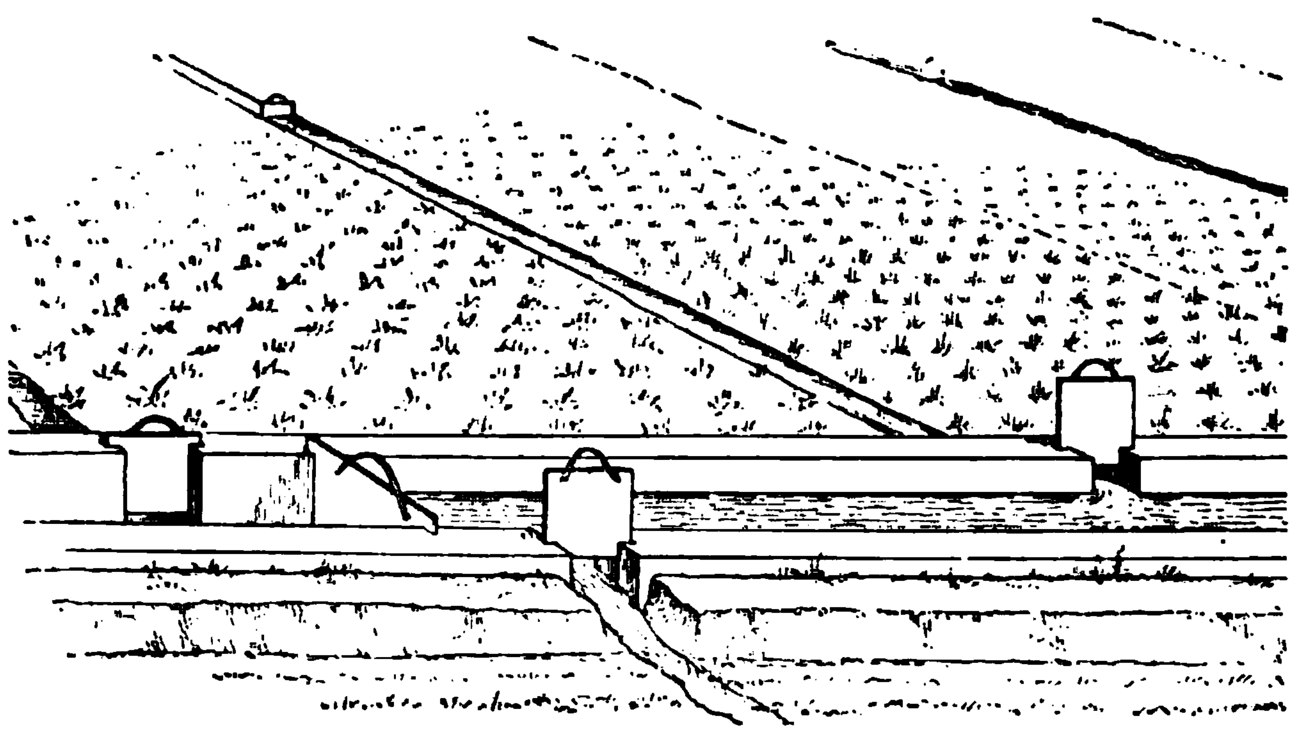


FIG. 88. — Channels and gates for sewage irrigation.

which naturally follow the use of sewage insure a more careful handling of the product than is customary in ordinary market-gardening operations.

The methods of controlling and applying the sewage are similar to those employed in the use of ditch water. The accompanying drawing (Fig. 88) shows a portion of a field through which permanent channels have been constructed. These are made of concrete and provided with iron gates,

making it possible to wash out the conduits and clean them whenever necessary.

ALKALI.

Among the chief disadvantages which are connected with the practice of irrigation is the accumulation of alkali, or earthy salts, which under some conditions may ultimately ruin the cultivated fields. In most cases the injurious accumulation of alkali can be prevented; in others the circumstances are such that destruction seems inevitable. It has been noted on pages 224 and 227 that the excessive use of water upon the fields promotes seepage and movement of waters underground. These ultimately appear upon the surface in the lowest spots, where they may form marshes upon lands which a few years previously were dry and may have been highly cultivated.

The formation of marshy ground can often be prevented by suitable drains, so that in many parts of the country drainage must follow irrigation, and the two become parts of one general system for controlling moisture. The drain from one field often serves as an irrigating ditch for another. In the early days, before drains were built, it was asserted that malarial conditions prevailed around irrigated fields, and some alarm was expressed over the supposed increase of fevers or other diseases attributed to irrigation. There probably is no basis for such fear, and irrigated farms are consid-

ered as healthful as any part of the arid region, the climate of which ranks among the most salubrious of all portions of the country.

The waters from seepage reaching the surface may not be sufficient to produce marshy conditions, but, being evaporated, leave on or near the surface any salt which they may be carrying in solution. Only the pure water can escape, and any matter which was dissolved is necessarily left behind. The most easily soluble natural salts are those of sodium, the most familiar of these being sodium chloride, the ordinary table salt, sodium carbonate, commonly known as sal soda, or by the farmer as black alkali, and sodium sulphate or Glauber's salt. All of these, as well as salts of lime, magnesia, potash, and various other compounds, are likely to be present in small quantities in ordinary soils, through the result of the decaying or breaking down of various rocks which compose the crust of the earth. The water seeping through these soils and rocks, dissolves minute quantities of these salts and carries them in suspension until evaporation takes place.

Before irrigation is introduced the soluble material is found to be rather uniformly distributed through the soil. When water is applied to the surface in considerable quantities, this immediately dissolves the salts to the depth to which the water penetrates. When the supply is continuous, a part of the water may escape beneath the surface by

A. SEWAGE IRRIGATION AT PHŒNIX, ARIZONA.

B. SEWAGE IRRIGATION IN ENGLAND.

seepage and carry with it the salts in solution. This seepage water, travelling slowly underground for a distance perhaps of a mile or more, ultimately finds its way to the surface, where it may enter a stream and flow away, or may appear as moist spots on valley lands.

Water evaporating from these moist spots leaves behind the dissolved salts, and in course of months or years these substances may accumulate until they are visible to the eye as either a black stain or a white glistening salt. Thus a fertile field which is being cultivated year after year may become wet by seepage, through the development of irrigation at higher points in the valley, and the yield per acre rapidly increase, due to this supply of moisture and to the enriching material brought by the water. Soon, however, spots appear where the crops do not thrive, and an examination shows that the earthy salts, beneficial in small quantities, have become injurious and destructive by concentration.

Part of the water applied to a field, after saturating the soil returns gradually to the surface, to be evaporated, being drawn up by capillary attraction or by the action of the roots of the plants. If there is an impervious subsoil, nearly all of the water will, in time, thus be drawn up. In its passage downward the water, as previously stated, dissolves the soluble salts, and in its return to the surface brings these with it and leaves them when

evaporation takes place. Thus, in the original condition, the alkali may be distributed uniformly through 10 or 20 feet in depth of soil, and not be sufficiently great to be noticeable, so that with ordinary dry farming no difficulties are encountered; but when water is applied, the salts are brought toward the surface by the action just described, and are concentrated within a few inches of the top, where, if not removed, they prevent the development of the plants. There are some soils, as in Southern California, where an excavation, such as a cellar, will show on its walls the bright, glistening alkali. Here orchards have been successfully cultivated, but the artificial application of water would immediately kill these by bringing the alkali to the surface. Such conditions are extreme, but illustrate the necessity of taking certain precautions.

The accumulation of alkali can be frequently prevented by draining, the seepage water carrying away the salts into the streams when an ample amount of water has been applied to the surface. The alkali can thus be washed out by producing a rapid movement of the water away from the field, either on the surface or through the soil into drains. The mere flooding without washing away of the salts is not effective. It has been pointed out that where the chief difficulty arises from small quantities of black alkali or sodium carbonate, this can be neutralized in part by the application of land plaster, or gypsum. This, consisting of sulphate

of lime, changes the sodium carbonate into the less harmful sodium sulphate and makes the lands tillable.

There is always likelihood of a considerable amount of alkali in the soils of arid regions, since these have not been washed through countless centuries by copious rains, such as occur in the humid regions. More difficulty is experienced with clayey soils than with sandy, as the water passes rapidly through the latter, washing out the alkali, and the roots of the crops are more widely spread. Open, sandy soils do not become injured by alkali, except under extreme conditions.

CHAPTER X.

IRRIGATION LAW.

At the outset the layman, in looking up matters of law relating to the use of water in irrigation, is impressed with the apparent confusion and contradictions he finds between the theory, the practice, and the decisions of courts. There are, however, certain underlying broad principles which can be recognized, and in spite of the superficial confusion and apparent lack of agreement among judges deciding definite cases, these principles are, on the whole, being adhered to and given application in the majority of cases which arise.

Irrigation jurisprudence in our country is a relatively new subject when compared with other branches of the law, the decisions concerning which have come down through centuries of English and American judicature. It is also to a certain extent revolutionary in its tendencies, since many opinions concerning flowing waters which have been sustained by generations of lawyers must be modified to suit the conditions in the arid West. Nevertheless, the principles of equity and the methods of procedure are sufficiently elastic to take cognizance

of the altered conditions, and, following the needs of the people, gradually swing into line with them. This, of course, must be done by degrees, and some criticism is provoked by the slowness with which some judges grasp the basic principles and the imperative requirements of the arid region, resulting from its peculiar physical condition. These men are notably conservative; some of them, coming from humid sections, fail to realize at first the true situation, and occasionally their decisions seem to run counter to the underlying principles. Remedy has been sought in some states by elaborate legislation and codes of water law, but this has often served rather to complicate and delay matters than to expedite the best solution of the difficulties. A legislative act may, in the minds of its framers, fit the peculiar situation, and yet be unsuited to a still wider circle of interests, or to localities where different conditions exist. Many experiments in this line have been made, but none of them are wholly satisfactory.

A great deal is said about the endless litigation pertaining to water rights. It is true that in many communities where irrigation is still in what may be termed its formative or speculative stage, controversies arise; but in settled communities, where the artificial application of water has been carried on for many years and has been the means of creating homes and large property interests, — as, for example, in Southern California, — these matters

have been settled to a large extent, and litigation concerning water rights cannot be considered as more frequent than that relating to land titles or to any other of the important transactions of daily life.

One of the principles which is being firmly established by court decisions is that pertaining to the original ownership of water by the people, as a common stock to be drawn from by individuals through rights which they acquire or hold by actual beneficial use, subject to public control under the police power or as a public use. All claims to water are, under this principle, limited to actual and beneficial use. The common stock of water is limited in quantity, and until all of it is put to beneficial use, persons desiring to thus employ portions of it are at liberty to do so, provided they do not interfere with the rights of others. Whenever this use is abandoned, the water returns to the common stock, to supply the needs of others. The fundamental principle is that beneficial use is not only the foundation and basis of the right, but likewise the measure and the limit thereof.

One of the most striking differences between the law governing the use of water in the arid region and that governing its use in humid regions grows out of the diametrically opposite way in which the streams, whether above or under the ground, are regarded by the lawmakers of the two sections.

The common law of the United States, brought from England, has for its object the preservation of the natural streams in their channels without diminution or disturbance. Each owner of land bordering upon a stream or through which a brook flows is protected against any change in the course or behavior of the stream, except from natural causes; and he in turn is prohibited from bringing about any modification which may affect other landowners below or above. This requirement, useful where water is not needed for irrigation, is directly contrary to the vital necessities of the arid region. It is impossible for agriculture to exist there unless water is taken from the streams. The first step toward settlement of the dry land, one taken even before houses are built, is the diversion of water from the streams. Not only is water thus carried upon adjacent valley lands, but it may be conveyed across natural divides, and the excess allowed to flow into an entirely different system of drainage.

The law of riparian rights must apparently be set aside at the very outset because of the necessities of occupation and settlement. In reality, however, it may be considered, not as being absolutely repealed, but as modified to suit the difference in climate. In the state of California, where both humid and arid conditions prevail, riparian rights have from the first been recognized, but the decisions of the courts have finally interpreted these

to mean that riparian proprietors are entitled to certain privileges only to the extent to which these have been utilized. That is to say, a landowner cannot enjoin a diversion of the water on the stream above him unless it interferes with some beneficial use by him of the water; if, however, he was using the stream to water a hundred cattle, and for nothing else, he could compel sufficient water for these cattle to be allowed to flow in the stream, but the remaining water, which may be a hundred or a thousand times the needs of his cattle, can be taken out for the irrigation of dry lands, provided no other beneficial use by lower proprietors is interfered with. In other words, riparian rights can be enforced only for the protection of the beneficial use to which the water has been put by the riparian owner. Although, as a naked legal right, the right of the riparian owner to the undiminished flow of the stream may be conceded, yet, when it comes to the remedy for its infringement, he practically has none, unless he can show, as a basis for his application for an injunction, that there is an interference with some beneficial use of the water by him. The basis of a riparian owner's right, like the right of an appropriator, is thus resolved back to the same principle — that of beneficial use.

This view of the right to take or appropriate the unused flowing water involves the consideration of the ownership of streams. There can be no question as to who owns the land through or along

which a stream flows. Individuals or corporations may unquestionably own the lands and the ditches or structures conveying water, but the actual body or corpus of the flowing water itself cannot, from its very nature, be classed as property which is capable of ownership by a person. It is held that in the arid region, where the land originally belonged to the United States, and where portions have been disposed of, the unused waters both above and under the government lands still belong to the government as part and parcel of the land.

Under federal statutes and state laws the use of the water is guaranteed to certain individuals to the extent to which they put it to beneficial use, and usually in the order in which they have thus employed the water. In theory, at least, the man who first irrigated 10 acres should continue indefinitely to have enough water for his 10 acres, while the man who next irrigated 20 acres can have sufficient water for his area only when it is apparent that the first man can also have his share; and so on, each person receiving an amount of water sufficient for the needs of his cultivated tract in the order in which this was put under irrigation (see p. 79).

This is known as the law of priorities. In theory it is extremely simple and just, but in practice it may be very complex, and its operations apparently unfair. For example, after a country has been settled for a generation or more, there does not seem to be any good reason why a

certain individual, who perhaps may be the poorest farmer of the community, should always have ample water simply because the man from whom he purchased or inherited his farm happened to take out and apply water a few days or months before his neighbors did.

A strict determination of priorities also leads to waste of water, as the earliest settlers may have been located at considerable intervals along a stream, 10 or even 50 miles apart, and on the lower, poorer lands, and so situated that water can be taken to them in small quantities only at great expense and loss of volume. As the country develops, and every drop of water is needed, the equities seem to demand that the priorities which at first were fair and just should give way to the largest and best use of the flowing streams. Ten men should not be deprived of the use of the life-giving fluid to satisfy the claims of a single individual. If water were a property in the sense of land, this consideration could not arise; but if it is something which belongs to the public, to be enjoyed by the greatest number, the course of events must bring about a gradual readjustment by a series of compromises or exchanges, such as has eventuated in the Cache la Poudre Valley of Colorado and in other parts of the arid region.

Instead of distributing water strictly according to priority of time, there has arisen in certain localities a system known as prorating water, or

dividing it proportionally to the amount available. This may be considered as the opposite extreme or alternative of the exercise of prior rights. In the simplest form this is practised by farmers living along a ditch which they have built in common and have enlarged from time to time. Each man shares in the water in proportion to the amount of labor he has put upon the construction, this being based presumably upon the area of land which he intends to irrigate. No consideration is given to the fact that one man near the head of the ditch irrigated certain tracts before other farmers, who may be at the lower end or upon an extension, commenced to irrigate theirs. In times of scarcity the first user of the water receives the same proportion of his usual share as his associates, who may be later comers, receive of their shares. Along extensive canal systems the strict application of priorities must occasionally give way in times of scarcity to a proportional division of water.

Even in localities where theoretically water is divided according to priority of appropriation, there is practised a considerable amount of prorating. It is impossible in a community to deprive a third or a quarter of the people of water, and compel their crops to be destroyed, in order to give the full appropriation to a favored few. Priorities are also, for administrative purposes, occasionally lumped, particularly in Utah, where a group of farmers who irrigated before 1870 share equally,

while those who irrigated from 1870 to 1880 are considered as holding secondary claims, and share in common, dividing what is left after the priorities are supplied, and so on, a general priority of right by groups of irrigators being recognized, and within these groups water being distributed proportionally.

There is a tendency, as the country develops, to abandon the strict observance of priorities, and ultimately, when all of the land has been brought under irrigation, to prorate the water. This is essential to the utilization of the available supply by the greatest possible number. Experience has shown that in the economical management of any large irrigation system water must be apportioned to the different laterals with respect to physical conditions and needs rather than to the strict construction of the priorities of the various irrigators. In the same way the apportionment of water from the rivers, to accomplish the most good, must ultimately be along natural lines rather than be based upon arbitrary systems resulting from the accidents of location of the first settlers.

It has been held by able advocates that the right to the use of the water becomes inseparably appurtenant to the land upon which it is used, so that if the land should be washed away by the shifting of a river in flood, the right to the use of the water would be extinguished. On the other hand, it has been held that the right to the use of

the water vests in the person who puts it to beneficial use, and becomes appurtenant, but not inseparably appurtenant, to the land irrigated. In this case, the owner of the land would have the right, if the rights of the other persons were not affected thereby, to change the use from one piece of land to another; but the right itself could only be held as appurtenant to some piece of land — in other words, there would not be a floating water right owned separate and apart from any land. The practice and the current of judicial decision throughout the arid region seem to be more in accordance with the latter view. A man irrigates a certain tract, and acquires the right to the continued use of a definite quantity of water for that purpose; a portion of this land may become swampy by seepage or injured by alkali, or he may purchase additional adjacent land or a farm lying farther down the canal, where the soil is better. Few people would dispute his right to use the water upon this contiguous or neighboring land, and he would continue his farming operations undisturbed, provided that in so doing he did not interfere with the rights of others. He might even arrange to receive his water through another ditch, and a considerable number of his neighbors might join with him. If, however, by so doing, the enjoyment of other persons in their vested rights should be injuriously affected, they would have the right to prevent such changes.

When we consider, however, not the right of the individual irrigator, but that of a canal company, the question becomes more complicated, and it may be necessary to distinguish between rights to divert water, rights to carry it, and rights to furnish water to users and charge therefor; these being distinct from the right to have the use of the water for actual irrigation upon the land. These various rights or privileges which lead up to the controlling factor, that of actually using the water, have not been clearly distinguished, but for convenience of discussion each may be considered as being separate.

These several rights of diverting, carrying, and supplying water to users are usually considered to be enjoyed by a canal company as a public agency in the nature of a carrier. There is no actual ownership of the water in the same sense that the canal and regulating works are owned; but while the water is in the canal, the company may be said to stand in the relation of a trustee, conveying the water to the persons who have the eventual right to put it to beneficial use. The company, if it owns land, may also have the right to the use of the water, but only to the extent to which the water can be put to beneficial use.

The rate charged for carrying the water is in several states fixed by the county commissioners. The manner in which the water is conveyed to the places of use, as well as the point of diversion, may

be changed, when by so doing injury to other interests are not involved.

Canal companies, as appropriators, are allowed to divert water from the streams, and are given reasonable time in which to begin the work, after posting the notice of appropriation; and irrigators who may wish to use the water are also allowed a reasonable time in which to complete the act of appropriation by applying water in the cultivation of the soil. No definite rule has been established as to what constitutes this reasonable time, though the usual legal rules concerning due diligence are generally applied. It has been held that when the water is thus used the right under the appropriation relates back to the time when the notice was posted, or to the time when water was diverted from the stream by the canal. The public records of these matters, which in some states are required to be kept by the county officials, are often extremely defective as regards the various claims and times of appropriation, the facts being usually established, if at all, by testimony taken in disputed cases.

In one state, Wyoming, rights to use water cannot be obtained until application has been made, and the state engineer has ascertained whether there is unappropriated water. The conditions in this state are unusually favorable to such a system of control, as the altitude of the state is high, limiting farming operations, the water supply is large,

and the ditch systems are relatively simple. The attempt to introduce a similar system in other states has not as yet been successful, and there appears to be a fear on the part of irrigators that their existing rights may be jeopardized and further developments prevented by the exercise of a control beyond that of the ordinary course of law.

The belief is widespread that it is preferable to allow developments to proceed under existing laws and customs, modifying these from time to time in detail as may be necessary, rather than to attempt by legislation to bring about ideal conditions, whose success depends largely upon an ideal administration. Although controversies arise, it is recognized that the present is a transition period, and that the communities which have been let alone to work out their own methods of apportioning water have, as a rule, succeeded better than those in states where radical legislation has been attempted.

CHAPTER XI.

STATES AND TERRITORIES OF THE ARID REGIONS.

EACH portion of the arid region possesses certain peculiarities of topography, climate, water supply, and cultural conditions. In discussing these it is convenient to consider them by political divisions, since the latter are easily recognized by name. Each state and territory is so large that it embraces usually a number of distinct climatic conditions, but in a brief review these may be classed together. For convenience the states and territories are here taken up in alphabetical order; they are: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

The following table gives the extent of irrigation at the beginning and end of the decade 1890–1900, and shows the gradual increase of this method of tilling the soil. The location of the irrigated areas is shown in Fig. 14, p. 54, together with the irrigable lands. The possible water supply is given in the last column of the table on p. 55 in millions of acres. There is water enough for over 60,000,000 acres if fully conserved by reser-

voirs or developed by wells, tunnels, and diversion canals.

AREA IRRIGATED.

State or Territory.	1890.	1900.
	Acres.	*Acres.*
Arizona	70,000	190,000
California	1,200,000	1,500,000
Colorado	1,000,000	1,400,000
Idaho	230,000	600,000
Montana	380,000	1,000,000
Nevada	240,000	510,000
New Mexico	95,000	200,000
Oregon	180,000	400,000
Utah	300,000	650,000
Washington	100,000	150,000
Wyoming	250,000	600,000
Subhumid	70,000	100,000
Total	4,115,000	7,300,000

The total area of these states has been given on p. 6. A comparison of this with the acreage irrigated shows that the land cultivated in this manner forms less than 1 per cent of the total extent of most of these states. It is not to be supposed that the whole of the arid region is irrigable, but it is highly probable that the area can ultimately be increased until ten times as much land has been brought under cultivation. The size of these states is so great that it is impossible to form a clear conception of their extent without making comparisons with other political divisions

FIG. 89.— United States compared with foreign countries.

in the United States and with some of the countries of the Old World. A single county in one of these Western states or territories may be larger than one of the older states of the Atlantic seaboard. To bring out this comparison Fig. 89 has been prepared, showing the outlines of the states. Across these have been lettered the names of several foreign countries whose area is very nearly equal to that of one or more of the states. For example, Spain has about the same extent as Utah and Nevada. Italy is approximately equal in area to Arizona, or to the Philippine Islands. Various other interesting comparisons are afforded in the East as well as in the West.

Similar comparisons are made on Fig. 90, which shows only the western portion of the United States, and with a little different combination of foreign countries. In particular, the states Oregon and Washington are seen to be equivalent to Great Britain, Ireland, Denmark, and Switzerland. Having in mind the great difference in population, we cannot fail to be impressed with the opportunities for increase of population and industries, especially as the resources of these Western states are of great extent and have hardly yet been exploited. There is apparently no reason why our Western states should not, in the distant future, be capable of furnishing homes and profitable occupation for as large a population as some of the countries whose names are placed across

them. The ultimate realization of such conditions rests, however, largely upon the treatment which

FIG. 90. — Western United States compared with foreign countries.

in the near future shall be accorded to the water resources, especially in the way of guarding these from speculative monopoly.

ARIZONA.

This territory, not yet admitted as a state, embraces 112,920 square miles, or 72,268,800 acres, in the driest and hottest part of the United States. Its population in 1900 was 122,931, nearly equal to that of the states of Nevada and Wyoming combined. The average for the whole territory is about one person to the square mile. In area the territory is a little larger than Italy, which has a population of 33,000,000, and a little smaller than the United Kingdom of Great Britain, with 41,000,000 people. The principal part of the population is in the Salt River Valley, in the vicinity of Phœnix, the capital city. The land here, as well as in many other parts of the territory, is extremely fertile, and lacks only an adequate water supply.

Increase of population and industry is limited directly by the possibilities of water storage. More land has already been brought under ditch and partly cultivated than can be supplied with water in ordinary years. Great tracts of country can, however, be utilized for home-making when the waters which now run to waste are carefully held for time of need.

Not only is the necessity for water storage greater in Arizona than in any other part of the United States, but the opportunities for constructing reservoirs on a large scale seem to be best there. There are in the territory a considerable

IRRIGATED VINEYARD NEAR PHŒNIX, ARIZONA

number of valleys whose position and form offer unusual facilities for holding the occasional floods.

Considering the territory as a whole, there are two distinct provinces, separated by a line of cliffs or mesas extending diagonally from northwest to southeast. Above, or north of, this line the country may be pictured as a plateau having an elevation of approximately 6000 feet, much of it covered with pine forests. The surface is undulating, and mountain masses rise from it. The rivers have cut enormous canyons in this plateau, the Grand Canyon of the Colorado being one of the most stupendous gorges in the world.

The smaller tributaries of the Colorado flow in narrow gorges 1000 feet or more in depth, and the small streams which occupy the bottoms of these cannot be taken out to irrigate the upland. Agriculture without the artificial application of water is carried on to a small extent, especially on the higher plateaus, and some irrigation is practised wherever sufficient ground can be found along the mountain streams. The northern part of the territory cannot be considered as having large opportunities for the creation of homes when compared with the southern part.

From the south front of the great escarpment or mesa a number of streams flow southerly, joining to form Salt River and its large tributary, the Verde. These unite and flow westerly through a broad valley, entering Gila River, which con-

tinues southwesterly across the territory into Colorado River. The valley of Salt River on the south merges imperceptibly into the broad desert traversed by the Gila and reaching beyond the Mexican border. There are millions of acres of good land in this area, but only a small portion can ever be supplied with water, even after all the possible reservoirs have been built and artesian wells constructed. Since the maximum possible supply falls far short of the needs of all the land, the remainder must always be barren, unless some desert-loving plants valuable to man be discovered and introduced.

A short distance below the junction of the Salt and Verde a number of canals, heading on one side or the other of the stream, take out all of the ordinary flow and carry it to the lands in the vicinity of Phœnix. The altitude here is about 1000 feet, and the climatic conditions are such that oranges and other citrus fruits thrive, and in some localities dates have been successfully introduced. The principal forage crop is alfalfa, of which from five to seven cuttings a year are made if ample water is available. This enables the farmers to produce a large amount of hay from a relatively small acreage. With other products there are usually two crops each year, and sometimes more, the ground being immediately cultivated and planted after each harvest. Thus, with continuous warmth and sunshine and with the necessary water, in-

tensive farming is practised, and it is estimated that a family of five persons can be well supported upon twenty acres, or even less, if covered with producing orchards.

Only a small portion of the good land is in actual use, the amount appearing almost insignificant on a map of the territory. This can be greatly increased by water storage, and in a less degree by deep or artesian wells. Around the Salt River Valley, on both the north and the east, among the mountains, are a number of storage sites, the most notable of these being at the junction of Tonto Creek and Salt River. Careful surveys of several of these localities have been made, plans prepared, and cost and benefits estimated. These investigations should be extended to include every possible locality.

South of the Salt River is the Upper Gila, a stream somewhat smaller, or furnishing a less amount of water. Along its course in the eastern part of the territory are several broad valleys, the most noteworthy being in the vicinity of Solomonville. Here, as in many other parts of the territory, Mormon pioneers have taken out ditches and brought large tracts of land under cultivation. Farther down, canals have been taken out to cover land southeasterly from Phœnix, in the vicinity of the town of Florence, and the supply here has been decidedly diminished by the diversions at points above.

Still farther west, and down-stream from Florence, near the junction of Salt River, is a large tract of desert land intersected by small, steep mountains which seem to rise out of the nearly level floor. This is the Gila River Indian Reservation, set aside for the Pima, Papago, and Maricopa Indians. These people have always been tillers of the soil, having practised irrigation long before the advent of the whites. Like most agricultural natives, they have been peaceable and friendly, and have even assisted immigrants in defending themselves from attack by the savage Apaches who dwell in the mountains near the head waters of the stream.

With the gradual diversion of the waters of Gila River in the vicinity of Florence, and particularly in the Solomonville Valley, the quantity in the river has been diminished, until for several years in succession there has not been a sufficient amount for the Indians. They have been forced to depend upon chance support, and, induced by hunger, to steal the cattle of their white neighbors. Their children have been sent to school and educated, but, on returning to their homes, find nothing to do, as farming cannot be practised without a water supply. To prevent actual starvation, the government has appropriated money for feeding these Indians, and while going to great expense in education, is at the same time pauperizing the people.

To enable these Indians to again become self-supporting, it is essential that they be provided with an ample water supply. Many investigations have been made, and it has been found that there are a number of places on the Gila River where reservoirs of large size can be built. It is not practicable, however, to construct small reservoirs, as these would be quickly filled with silt, and the expense of building dams for them would be nearly as great as that of structures for reservoirs of the largest possible capacity.

The best place found upon the Gila River is near San Carlos, on the White Mountain Indian Reservation, occupied by the Apaches. Here can be built a reservoir sufficient to supply the needs of the Indians and to reclaim at least 100,000 acres of government land. This land, if thrown open to homestead entry, subject to payment for the water, would doubtless be taken up immediately, and the government reimbursed for its outlay.

There are a number of smaller streams in the southern part of the territory, each of which is now utilized to its full capacity when at ordinary stages. The floods of these streams could be stored and used upon tracts of government land, thus providing opportunities for many additional farms. The violence of some of these deluges is illustrated by Pl. VIII, giving a view of the bridge across Salt River, which was partly destroyed by a rush of water that carried out practically all of the dams

and head gates along its course. This is exceptional; but it is possible to provide storage to hold the ordinary floods on many of the streams and reduce the violence of the extraordinary ones.

There is probably no place in the United States, except possibly in Southern California, where the marvellous results accomplished by irrigation are more conspicuous than in Arizona, particularly in the Salt River Valley in the vicinity of Phœnix. Here, on the broad desert valley, bare of vegetation except for an occasional dry, dusty group of thorny plants, the venturesome pioneer took out small ditches, many of these following the ancient, almost obliterated, lines of the canals of the prehistoric agricultural Indians, the ruins of whose towns dot the plains. Under the brilliant and intense sunlight, the moistened soil yielded bountifully, and the small ditches were rapidly enlarged and canals built to cover more and more ground.

The dry climate, especially of the winter season, is found to be advantageous to human beings as well as to plants, and renewed vitality has been given to many an invalid from the cold and stormy North. The success attained with oranges and other citrus fruits, as well as with grapes, prunes, plums, and various fruits needing the warm climate, has led to a rapid widening of the area devoted to vineyards (Pl. XLVII) and orchards, these revenue-producing vines and trees being supplemented by luxuriant growth of palms, rose bushes, and innu-

DRYING APRICOTS.

merable varieties of ornamental and flowering shrubs. The delicate house plants, tenderly cared for in the North, here develop to wonderful size and variety, being hardly recognizable in the sturdy, treelike forms which threaten to bury the suburban houses in a perfect jungle of flowering branches and creepers, all the result of watering the dusty plains.

The fruits of the Salt River Valley are not brought into immediate competition with those of Southern California, as it is possible to put them upon the market at an earlier date, and a certain advantage is given in a shorter haul toward the Atlantic and Gulf states, this being an important item in the handling of the fresh fruits. Great quantities are thus shipped out; but the principal dependence is placed upon dried fruits (Pl. XLVIII) and upon alfalfa, which is used in fattening cattle that range throughout the year upon the mountains adjacent to the Salt River Valley and upon the plateaus of the northern part of the state.

The development of irrigation and the enlargement of the cultivated area is continuing up to the limit of the water supply, and many canals have been built or are projected to cover areas for which in ordinary seasons there is not sufficient water. In order to bring about economy, some of the ditches and canals have been consolidated, reducing the losses by seepage and evaporation. This is the first step in the evolution of a system of con-

trol which must ultimately be worked out to suit the conditions in each locality.

The next and most important step in growth is the construction of reservoirs wherever practicable, since there is need for all of the water which can possibly be held. The erratic floods are too valuable to be allowed to run to waste, destroying property along their course. With increase of population and introduction of improved varieties and new species of fruits, the value of the products per acre must steadily rise to a point where the construction of even the most expensive reservoirs now projected will more than justify the outlay.

CALIFORNIA.

Excepting Texas, California is the largest state in the Union, having an area of 155,980 square miles, or a little over three-fourths that of France or Germany. It includes almost every variety of topography and climate, from elevated mountain masses with perpetual snow down to fertile and well-watered fields and to the barren, torrid deserts 300 feet below sea level. The most notable feature is the great central valley of the state, drained in its northern part by the Sacramento River and in the southern end by the San Joaquin River. These rivers, flowing toward each other from opposite directions, finally merge, their united waters being poured westward through the Golden Gate into the Pacific. On the east of this great valley are the

lofty, snow-capped mountains known as the Sierra Nevada, from which come many streams tributary to the great rivers just mentioned. West of the great valley, and between it and the ocean, are the irregular groups of mountains which make up the Coast Range. Among these are long, narrow valleys. To the north of San Francisco Bay these mountains are for the most part humid and well-forested, but to the south they are dry and support only a scanty vegetation.

The southern part of California is a region differing both in topography and in climate, and has such distinctive features and interests that there has resulted an occasionally expressed desire on the part of the people to become an independent state. The southern prolongation of the Sierra Nevada, curving around the head of the San Joaquin Valley, forms a barrier between Southern California and the remainder of the state. The railroad crosses over what is known as Tehachapi Pass. Below this is the Mohave Desert, which extends easterly and southerly to the Colorado River. A lofty range of mountains borders this desert on the west and cuts it off from the ocean. At the southern and western base of these mountains are several valleys opening toward the ocean, or extending to it, and having a climate such that citrus fruits of the best quality, nuts, and various semitropical plants are successfully raised. A dense population has gathered here in the cities

of Los Angeles, San Bernardino, Riverside, San Diego, and in many towns, and the well-distributed, though small, water supply has enabled a develop-

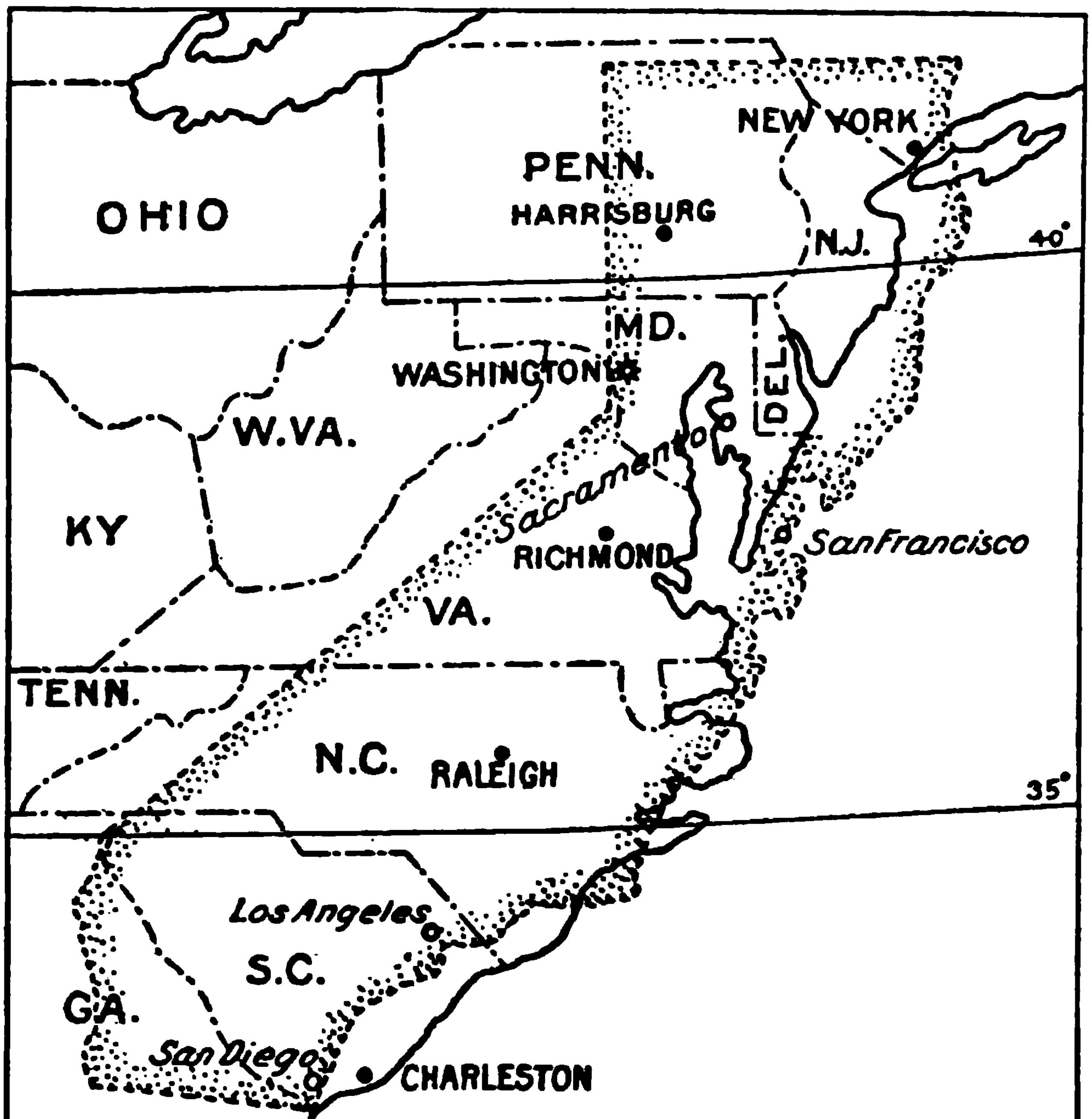


FIG. 91.—California compared with the Atlantic states lying in the same latitude.

ment of irrigation in the rural districts surpassing that found elsewhere in the United States.

The vast extent of California, with its surpris-

ing differences in climate, must be borne in mind when discussing the resources of the state and

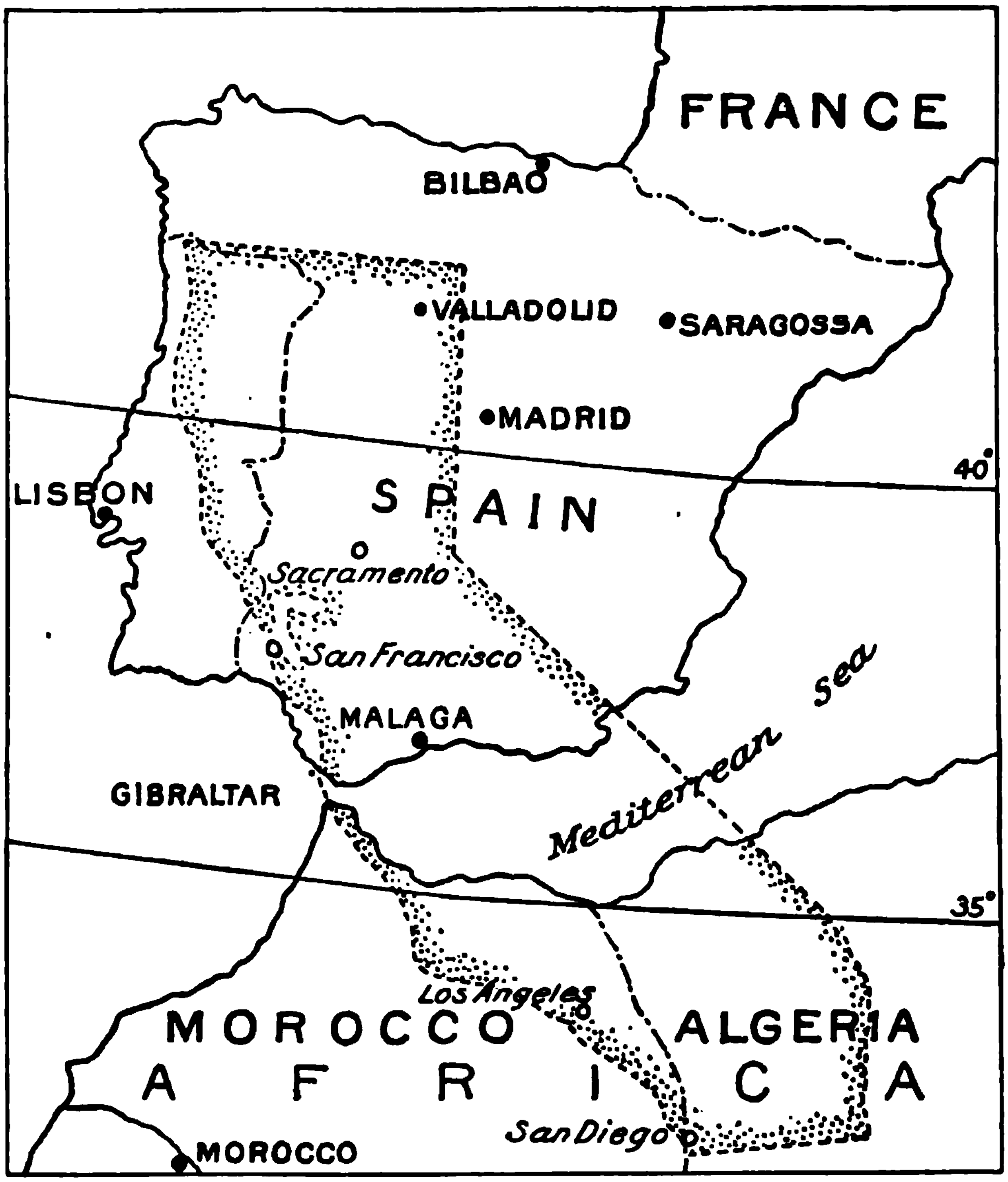


FIG. 92.—California compared with Old World countries lying in the same latitude.

the dependence of these upon irrigation. In the southern portion in particular all development and land values rest directly upon the ability to obtain

a water supply, while in the northern portion dry farming is generally successful and irrigation has value mainly as insuring a better crop or a higher-priced class of products. To obtain a more realistic conception of the extent of the state, Figs. 91 and 92 are given, these showing in outline the state of California as placed on a map of the Alantic coast states of this country, and on a similar map of Spain and northern Africa. In both of these sketches California is shown in its true position relative to distance from the equator, but in Fig. 91 it is reversed, or turned over, so that its coast line will coincide nearly with that of the Atlantic coast.

By reference to Fig. 91 it is seen that California extends from the latitude of northern Pennsylvania down to that of South Carolina and northern Georgia. San Francisco corresponds in position fairly well with Norfolk, Virginia, and San Diego with Charleston, South Carolina. It is interesting to note that in each of the portions of states included within the dotted outline of California, there is now a population nearly equal to, or exceeding, that of the entire state of California, which is, in round numbers, 1,500,000. New Jersey and North Carolina have each nearly 2,000,000 inhabitants. Maryland, with the District of Columbia, has a population almost identical with that of California, and eastern Pennsylvania far exceeds either of these. With the natural resources of

California so far exceeding those of the eastern Gulf states, it seems incredible that such great inequalities of population continue indefinitely. When a comparison is made of California with the Old World, as in Fig. 92, the striking difference in population is again brought out. Portugal has over 5,000,000 inhabitants, Algeria has nearly as many, and Spain has over 18,000,000.

The methods of irrigation and the habits of the irrigators are as diverse as the great extent of the state and the variety of climatic and topographic conditions would imply. In the more humid portions of the north, irrigation is not practised or is regarded as something exceptional or of doubtful utility. In the centre of the state, where the large rivers pour their floods from the Sierra Nevada out into the dry valley, great canals have been built and water is lavishly used. South of Tehachapi, where the rivers are comparatively small and population is dense, there is the most complete conservation of scanty supplies, and irrigation is regarded as the highest triumph of the agricultural art. Great dams have been built, such as the Sweetwater, Otay, Hemet, and Bear Valley, for storing floods, and expensive cement-lined ditches and wooden flumes have been constructed for taking the precious fluid to the fields with the least possible loss.

Among the foothills on the eastern side of the Sacramento and San Joaquin valleys gold was early

discovered in placers, and these were worked by means of water taken out by innumerable flumes and ditches. With the decline of this business, due largely to the so-called anti-débris law, many of these ditches were used to irrigate little sidehill farms, and it was found that valuable fruits could be raised, particularly oranges, on the lower hill slopes. Thus many of the structures originally made for mining have been repaired and gradually enlarged for purposes of irrigation.

The greater part of the valley of California, in spite of the small rainfall, has been used for growing wheat. This has been successfully cultivated even upon the adjoining foothills. The large wheat farms cultivated without irrigation are, however, being gradually encroached upon by orchards and by alfalfa fields, as water has been brought out from the mountains. The tendency is to subdivide the great holdings of the Sacramento and San Joaquin valleys. The application of water makes possible the creation of a considerable number of small irrigated farms in place of one dry farm devoted to raising grains. This results in a decided increase in population, since a family can find support upon 40, or even 20, acres of land planted in orchards and vineyards, while ten or even a hundred times this area may be devoted to a single wheat farm.

Irrigation construction in California has proceeded with relative slowness during recent years,

partly because of the effect of the operations of what is known as the "district law," passed in 1887, allowing the creation of irrigation districts in some respects similar to municipal organizations, but having a single object; namely, that of delivering water in sufficient quantities for the utilization of the lands embraced within their borders. One of the principal features of this law has been the authority conferred to bond the district, and to dispose of these bonds for the purchase or construction of irrigation works. Without entering into details, it is sufficient to say that over forty irrigation districts were formed and bond issues authorized to the extent of millions of dollars. Through lack of sufficient safeguards the districts received comparatively little benefit from the disposal of these bonds and the property holders awoke to find themselves struggling under heavy debts, with little or no improvement as regards water supply. Many of the bonds issued are comparatively worthless, and discredit has been cast upon reclamation methods of this character.

The way in which the canals lead out from the principal rivers in the San Joaquin Valley is illustrated in Fig. 93, which shows the canal system from Kern River, California. The dotted lines are contours and show points of equal elevation, the lowest being 300 feet above sea level. The higher canals are taken out as nearly as possible along these contours, in order to cover

the most ground. Other canals lower down the river follow down the slopes, the resulting

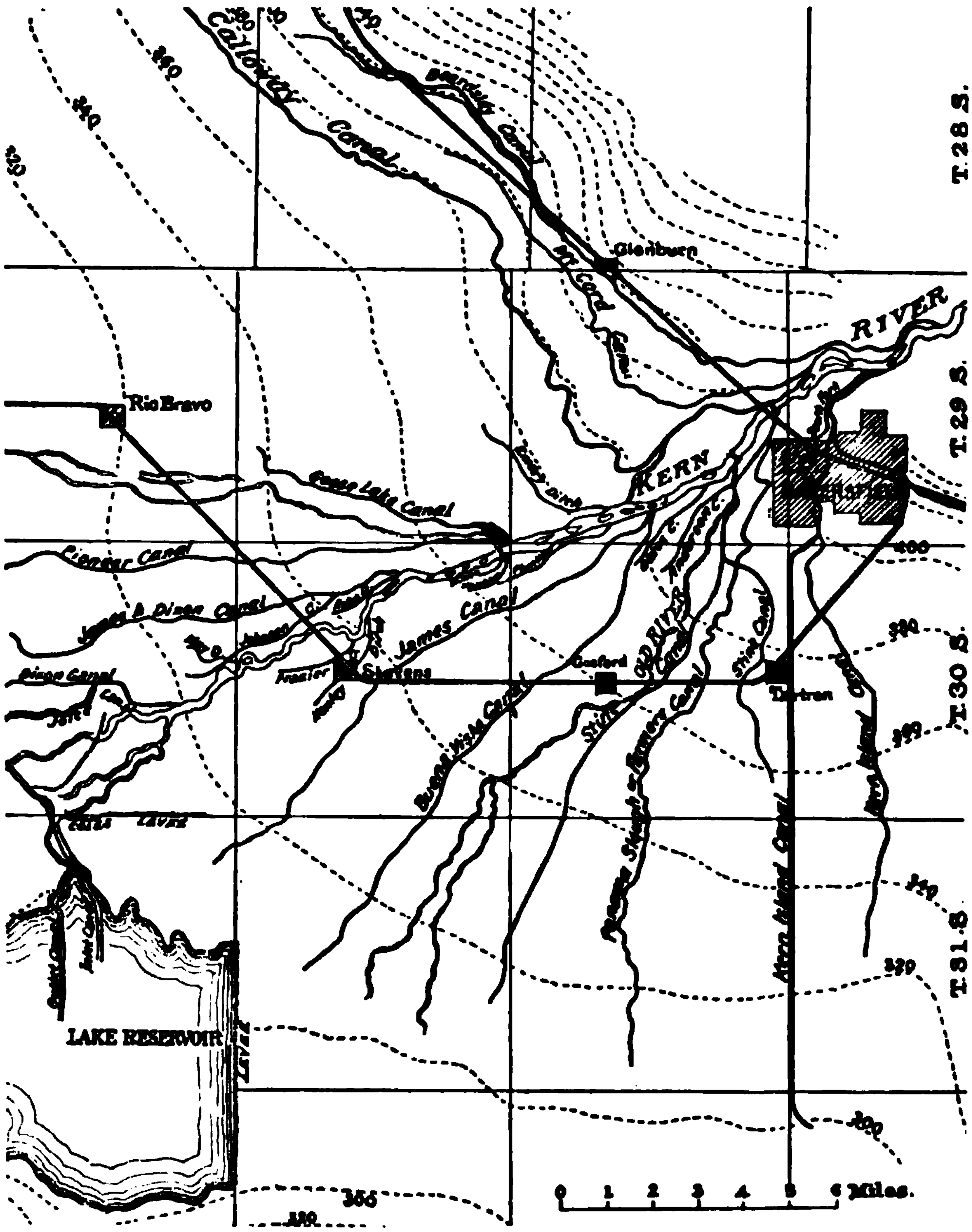


FIG. 93.—Canal system from Kern River, California.

arrangement being fan-shaped, fitting the topography. Water is usually had in abundance from

A. IRRIGATION OF VINEYARD IN SAN JOAQUIN VALLEY, CALIFORNIA.

B. IRRIGATION OF ORCHARD IN SAN JOAQUIN VALLEY, CALIFORNIA.

these canals, and is somewhat lavishly employed, as illustrated on Pl. XLIX, giving views of the irrigation of an orchard and of a vineyard. For alfalfa, with its three to five cuttings during the summer, even more water is employed than in the orchards, in order to wet the ground thoroughly after the removal of each crop. With the gradual increase of orchards and the extension of land under intensive farming, less amounts of water are being wasted.

In striking contrast to this lavish use of water is the economy practised in Southern California, where the little rills from tunnels driven into the hills or from wells are carefully guarded and carried into pipes, to be distributed underground or brought to the surface near each garden plant or orchard tree, as described on p. 207, under the head of subirrigation. The economies practised in the southern part of the state must ultimately be employed even in the great valley with its large water supply, for this, although impressive to the eye, is far short of the needs of all the good land which can be irrigated.

The drought of recent years has borne particularly hard upon the irrigators of Southern California, where the supply of water was already limited, and many enterprises for obtaining water have been undertaken which otherwise would not have been considered. Almost innumerable wells have been sunk in the country about the vicinity of San

Bernardino, and from there to Los Angeles, these being located on the slopes of débris coming from the canyons, and also in and adjacent to the stream channels. Some of these wells have yielded large amounts of water, and in a few localities artesian conditions have been found, resulting in a very valuable contribution to the wealth of this part of the state.

Not only have ordinary vertical wells been constructed, but what may be considered horizontal wells have been dug, with the idea of intercepting small amounts of water which may be progressing slowly beneath the surface. These consist of tunnels run on a slightly rising grade into the gravel slopes, or even into the rocky walls of the valley or canyons. Sometimes these tunnels, after penetrating the solid rock, turn and go beneath the bed of a stream, in the hope of finding in the deep deposit of boulders and cobblestones some water which can be diverted. As a result of this undercutting, several controversies have arisen, persons using the surface flow claiming that diversions from the pervious material, even though lying far beneath the surface, are in effect an unlawful taking away of the flow. It is argued that the stream cannot continue on the surface unless the underground passages are completely filled with water, and that by draining these an equivalent amount is sooner or later taken from above. This matter is of importance not only in California, but

elsewhere, and has been a point at issue in an important lawsuit over waters of Los Angeles River, as noted on page 235.

The results attained by this complete conservation of the water supply of the southern part of the state, and the utilization of comparatively insignificant sources as well as those of considerable size, are shown in the wonderful increase of cultivated area and the high degree of perfection reached in the care and management of orchards and vineyards. The visitor to Southern California finds it almost impossible to conceive that the tracts now covered by trees and vines were only a few years ago a bare and apparently sandy waste, not fit even for grazing except after an unusual rain. He is further incredulous when told that the homes of comfort, and even of luxury, surrounded by palms and almost covered with flowering shrubs, have been paid for by the products of these small orchards, and that families are making a living and getting ahead in the world by the cultivation of fifteen, or ten, or even fewer, acres of land which before the introduction of water can hardly be said to have had any value.

Cities such as Riverside, Redlands, and Anaheim, and innumerable towns, with their thickly settled suburbs stretching out along the lines of canals or supply pipes, are not only monuments to the energy and perseverance of the men who founded them, but also living testimonials of the value of water

conservation. The system of supply, now grown to large proportions, may properly be classed with the wonders of the world. Surface streams have been controlled and underground waters brought to the surface, creating a volume of water whose value, measured by the results produced, runs up into millions of dollars.

One of the greatest matters of surprise has been the success attained during the trying season of drought which culminated in 1899 and 1900. There had been for a decade less than the normal precipitation, and for two years the rainfall had not reached one-half the average for the region; but, in spite of misgivings, the water supply, especially that from underground sources, did not diminish as would have been expected, and the numerous wells and the tunnels driven into the hills did not appear to be affected by the scarcity of precipitation. The extra care due to the realization of the need of economy resulted, not only in saving the fruits and crops, but in some instances the yield was actually increased over that of seasons when the water supply was abundant. It is probable that there is still to be had a large amount of water from underground, and that by the use of cheap power, such as that obtained by electrical transmission or by burning the crude petroleum produced in large quantities in California, great volumes of water may be pumped to the surface for raising high-grade fruits.

Not only has the underground supply not shown any notable diminution from the drain put upon it, but the seepage or percolating water in some of the springs or cienegas has actually increased. This is especially the case on San Gabriel, Los Angeles, and Santa Ana rivers. This latter river, rising in the mountains, flows upon the upper edge of San Bernardino Valley, the water being all taken out for irrigation or disappearing into gravel washes. At the lower end of the valley, where the outlet is through a narrow, rocky pass, water reappears upon the surface and a perennial stream is formed, as shown on Pl. IX, *A*. This stream, instead of becoming dry, as might have been expected from the increased use of water in San Bernardino Valley, has actually grown larger, and from the flow of about 25 or 40 second-feet of ten years ago it has risen to two or three times that amount. This is probably due to the results of more complete irrigation of the valley, the gradual saturation of the subsoils, and the progress of the water slowly by seepage from the fields where applied months or even years before down toward the outlet of the valley, again forming the river.

This careful conservation and complete development of surface and underground waters, and the conveyance and distribution of these in expensive conduits, as shown in Pl. L, have necessitated heavy expenditures and the annual payment of sums which seem very large when compared with

the cost of water elsewhere, as for example in the San Joaquin Valley. Under the Fresno Canal, which diverts water from King River, a water right, or privilege of purchase, is worth about $40 per acre. The annual charge for water is only 65 cents per acre. This is very cheap even for this valley. In this locality the water plane has risen to within 10 to 15 feet of the surface, and very little additional water is needed for irrigation.

In contrast to these conditions are those in Southern California. For example, under the Anaheim Union Water Company, in Orange County, water is sold at $4.80 per acre-foot and is considered cheap, but the company is reported to lose money each year and to make up the loss by an assessment on the water-using shareholders.

At Corona, or South Riverside, in Riverside County, the charge in 1900 was $15 per acre-foot of water. Owing to the drought, there was but one-half the usual amount of water delivered during the year. This supply is largely from a pumping system, and the charge for the year 1900 was above the average, owing to improvements that were made during the season.

Under numerous pumping plants near Azusa, in Los Angeles County, water has been sold for irrigation during the years 1898 to 1900 at from "3 to 5 cents per hour-inch"; this is at the rate of $18 to $30 per acre-foot. At Azusa the cost is $5 per acre irrigated from the Azusa Canal, which

REDWOOD STAVE PIPE 52 INCHES IN DIAMETER CROSSING WARMSPRINGS CANYON NEAR REDLANDS, CALIFORNIA.

diverts water from the San Gabriel River. At Ontario $10 per acre is charged each year.

At Hollywood, a suburb of Los Angeles, a charge of 10 cents per 1000 gallons is made for water, or $32.31 per acre-foot. The land is used for growing lemons, but the water rate is too high to permit of large commercial success.

The annual charge for the irrigation of citrus lands in Southern California varies from $5 to $30 per acre, and will probably not average far from $10 per acre irrigated, the supply being usually 12 inches in depth of irrigation water. In addition there is about 15 inches of winter rain. The citrus fruits in general need twice the water required by the deciduous fruits, and alfalfa usually has more than that used by either. Under the Gage canal system at Riverside, where citrus fruits are grown almost exclusively, and where the soil is somewhat porous, derived largely from granitic débris, with a good slope and with a rainfall of 6 inches in the winter, there was applied during 1900 about 2.2 feet in depth of water. This was an average for the entire system, and irrigation was practised every month in the year, owing to winter drought. Other estimates for this canal are given on page 218.

In Redlands the duty of water is usually considered as 12 inches in depth for citrus fruits, applied during the six months, May to October inclusive, the normal winter rainfall being 16 inches.

Under the Sweetwater system, in San Diego County, 1402 acre-feet of water served 3800 acres of citrus fruits from May to November, 1899, during a drought. Deducting for domestic consumption of water, this leaves .28 foot in depth applied. The trees survived and a crop was gathered, but this is regarded as an extreme case.

The importance of the fruit industry to Southern California may be judged from the statement that in 1899 the shipments of oranges aggregated nearly 10,000 car loads, valued at $7,000,000. The assessors report for the seven southern counties over 2,000,000 bearing trees, and over half as many non-bearing. The principal orange-growing locality is Riverside, which produced a third of all these oranges, and next Redlands and the Azusa Valley, each producing about 10 per cent of the entire output. The orange crop in the seven counties was produced from about 48,000 acres, or 75 square miles, of which about 40 square miles contained bearing trees. The first cost of the land, including the planting and care of orchards, has been estimated to be $25,000,000. The profits of the grower have been found to be 12 per cent. The orange land with water, but without trees, is estimated to be worth from $250 to $300 per acre, while with bearing trees the price ranges from a thousand dollars per acre up to double that amount for groves with fine location, navel trees, and first-class water rights.

COLORADO.

Among the irrigating states Colorado stands next to California in the amount of land watered. The crops raised are decidedly different, in both character and value, owing to the colder climate, which prevents raising the citrus or semi-tropical fruits for which Arizona and California have become celebrated. Large quantities of forage and the coarser staples are produced. Various portions of the state have acquired a more than local reputation for the production of excellent vegetables and deciduous fruits. For example, Rocky Ford, on the Arkansas River, is known throughout the country for its watermelons, and especially for cantaloupes. Greeley and vicinity have set a standard for potatoes, while Grand Junction has attracted attention by its peaches. Although equally good results are claimed for other rural communities, the reputation acquired by these localities testifies to the excellence attained.

Colorado has 103,645 square miles of land surface, a little less than the combined area of the six New England states and New York. Its population in 1900 was 539,700, or less than a twentieth of the population of these seven states, but its natural resources are in many respects incomparably greater. The state includes a considerable part of the Rocky Mountain region, noted for the valuable

deposits of precious metals and minerals. It extends on the east out over a portion of the high plains which rise from an altitude of about 3000 to 5000 feet or more at the foothills. These broad plains furnish excellent grazing in ordinary years, and occasionally a crop of cereals can be produced by careful cultivation, if favored by the occurrence of fortunate rains. Dry farming has been attempted at various points along the eastern boundary, and is carried on with a fair degree of success on the high divide which lies north and northeast of Colorado Springs. As a rule, however, it may be stated that irrigation is essential for success throughout the state.

The plains are traversed by two rivers, which receive their main supply from the Rocky Mountains: the South Platte, flowing toward the northeastern corner of the state, and the Arkansas, farther south and flowing easterly. Large canals and many ditches divert water upon the valley lands and adjacent plains, so that, during the summer at least, the beds of both rivers are dry long before reaching the state line.

The high plains, rising gradually toward the west, are suddenly intercepted, nearly half of the distance across the state, by the foothills of the Rocky Mountains and by the main ranges, which rise to lofty snow-covered peaks 13,000 feet and more in height. From the front range westward the entire state consists of mountains and broad

plateaus with relatively few valleys. Among the mountains, at elevations of 7000 feet, are a number of basinlike areas dotted with trees and known as parks. Here natural grasses abound, and by distributing water from the small streams over the surface large quantities of forage can be had.

The streams which flow westward from the main divide unite finally to form the Grand River or empty into Green River. These join to make the Colorado River of the West. The water supply is large, but the valleys are narrow, and as a rule there is more water than is needed for the agricultural land, so that storage here is of secondary importance. The principal problem is to lift the water to the benches or mesas along the streams, or to divert it by means of canals heading in the canyons, or by tunnels cut through intercepting rocky spurs.

In the southern part of the state, at an altitude of over 7000 feet, is the broad San Luis Valley, through which flows the Rio Grande on its way south into New Mexico. In spite of the altitude, and consequent cool climate, agriculture by irrigation is successfully practised for the production of cereals and for the growing of alfalfa and other forage plants.

The largest irrigated areas in Colorado are along the Platte and Arkansas rivers, and here the principal problem is that of increasing the summer supply by a thorough system of water storage.

The canals and ditches already built, taking water to land partly under cultivation, could probably utilize to advantage all of the water which can be conserved. The owners of these irrigation works have been gradually enlarging them, building private reservoirs, and adjusting among themselves a system of apportioning the water, so that the scanty supply may be divided in accordance with priorities and with various equities.

One of the principal tributaries of the South Platte is Cache la Poudre River, which supplies the farms in the vicinity of Greeley, a view of one of which is shown on Pl. LI. The summer flow of this stream has been increased by the diversion of the waters of Laramie River (p. 178), and also by the building of a number of reservoirs, both in the mountains and out on the plains. A complicated system of transfers of water has been inaugurated, by which the claims of one set of men are temporarily transferred to another, the natural flow of the stream being traded for an equivalent amount of stored water, and the reverse, so as to utilize reservoirs which lie at different altitudes and to enable the storage of water which otherwise could not be economically handled. Out of these apparent complications there is being gradually evolved a system of local water control, embracing the entire stream, and tending to do away with the rigid observance of priorities of right in favor of the largest and best use of the water.

IRRIGATING A WHEAT FIELD IN COLORADO.

The gradual evolution and adjustment of water rights on the Cache la Poudre and along the Arkansas is to a certain extent typical of the progress in other localities, where some of the lower canals have prior rights over those higher upstream. The latter are located in such a position that they can more readily take the water as it comes from the mountains, and it has been exceedingly difficult to keep the head gates of these upper canals closed in times of scarcity in order to force down the proper amount to ditches below. To assist in adjusting the various difficulties, associations have been formed and various agreements entered into. One of the chief obstacles to full development of the water resources lies in the fact that water storage has been begun on the head waters, not for the benefit of all concerned, but for one or two canals, thus introducing irritating complications, and uncertainty as to which portion of the water is stored and which is the natural flow. The importance of public ownership and control of natural reservoir sites has been mentioned on page 177.

IDAHO.

This state has a land area of 84,290 square miles, being slightly larger than the state of Kansas and a third greater than the whole of New England. The population in 1890 was 161,772, thus averaging about two to the square mile, as compared with a density of from 20 to 50 persons to

the square mile in the Eastern states. The greater part of this population is in the valleys along Boise, Payette, and Weiser rivers and on the head waters of Snake River, and also in the mining towns scattered through the mountains.

The form of Idaho is peculiar. Toward the north is a narrow prolongation, including the mountainous area between the states of Montana and Washington. The broad southern end includes the greater part of the valley of Snake River and the tributary country. This is mainly a broad, lava-covered plain, dry, dusty, and barren, except for a dense growth of sage brush and similar woody shrubs. The lava frequently appears on the surface, the rough, angular blocks giving a forbidding appearance to the landscape. A thin soil, often sandy, covers some of the lava, but where watered this, like most of the soil of the arid regions, has been found to be highly productive.

The head waters of Snake River are in the vicinity of the Yellowstone National Park. They flow in a general southwesterly course, out upon the lava-covered plains, bringing vast quantities of sand and gravel. Over the deposits thus formed the streams meander, rendering it possible to easily divert the water for agricultural purposes.

Soon after leaving the mountains Snake River begins to cut into the rocky surface, and with successive rapids and falls, as shown on Pl. LII, *A*,

A. TWIN FALLS, SNAKE RIVER, IDAHO

B CONSTRUCTING A CANAL BY MEANS OF A GRADER.

it works its way downward until it flows at a depth of 1000 to 2000 feet or more beneath the general level. Continuing in deep canyons, the river crosses the southern end of Idaho and then swings toward the north, the canyon walls giving place to broad, undulating valleys where the Boise, Payette, and Weiser rivers enter from Idaho and the Owyhee and Malheur rivers come in from Oregon. Here agriculture has been developed to a larger extent than elsewhere in the state. Leaving this open land, the river keeps northward, having cut for itself deep, gloomy canyons separating the Blue Mountains of Oregon from the characteristically named Seven Devils region of Idaho.

North of the Snake River plain are the Salmon River and other rugged mountains of the central portion of the state. From these a number of streams flow southerly toward Snake River, their waters disappearing in the pervious lava, and probably reappearing as springs in Snake River Canyon. These springs are almost innumerable and some of them have a volume of several hundred cubic feet per second. Within the mountains the valleys are narrow, and agriculture is practised to a limited extent, mainly in the vicinity of the mining camps of this rich mineral region.

In the eastern end of the state, on the head waters of Snake River, where the altitude ranges from 4000 to 5000 feet, the settlers, mostly Mormons,

have brought large tracts of land under cultivation. The altitude here is such that greatest success is had with alfalfa and similar forage crops and with small grain. Fruits are being raised only to a limited extent. Farther down the river, and especially in the western part of the state, in the vicinity of Boise, the capital city, and extending out along Snake River, fruits are of considerable importance, orchards of large size being devoted to the production of prunes, plums, apples, and pears, these being in addition to the ordinary farm crops. The altitude here is from 2000 to 3000 feet, and the almost continuous sunshine of summer is highly favorable to the production of fine fruits. Large and expensive irrigation works have been built below Boise, one of these being illustrated in Pl. LIII.

The flow of Snake River near the central portion of its course in the state averages in summer about 5000 second-feet, and ranges from a low-water flow of a little less than 2000 second-feet to ordinary floods of 50,000 second-feet. This volume of water, tumbling over cliffs such as those at Twin Falls, shown on Pl. LII, *A*, and Shoshone Falls, and shooting down the long rapids, not only adds to the picturesque attractions of the country, but at once suggests possibilities of the development of enormous water-power. Part of this has been made of use at American Falls near Pocatello, and at a point southwesterly from Boise.

WOODEN PIPE LINE ON PHYLLIS CANAL, IDAHO.

By developing this power to its full capacity it will be possible to create many industries and to pump water to elevations which cannot be covered by existing canals.

The waters of Snake River are by no means fully utilized for irrigation purposes, although a considerable number of ditches have been constructed, taking the water from the river at short intervals and covering land on both sides from Yellowstone Park down to American Falls; yet these have not notably diminished the flow of the stream, except at times of unusual drought. Below American Falls there are apparently no opportunities for taking out water, until points a short distance above Twin Falls are reached, and below this locality again, water cannot be brought to the adjacent upland until the valley widens out in the extreme western part of the state. Even here it has been found impracticable to divert water from the main river, and the valley land has been irrigated wholly from tributary streams.

By the construction of large canals heading above Twin Falls, and by the completion or enlargement of other projects now under way, it is probable that the summer flow of Snake River can be wholly utilized and that storage on the head waters may be necessary. Such complete development will mean a large increase in the population of the state, and will bring under cultivation many hundred thousand acres of vacant public land.

The principal town in the northern part of the state is Lewiston, situated at the point where Clearwater River enters Snake River. Here the valleys are very narrow, as shown on Pl. LIV, and are bounded in places by benches upon which some water can be taken from tributary streams, or to which a small quantity may be lifted by pumping. Fruits are successfully raised in these narrow valleys and on the higher lands wherever water can be had. Dry farming is practised on the rolling uplands (Pl. LVI), wheat being the principal crop.

MONTANA.

Montana is the third state in area, being exceeded in size only by Texas and California. Its land surface of 145,310 square miles is nearly as great as that of New England, New York, and Pennsylvania combined. The population in 1900 was 243,329, or less than two per square mile. This state is the most northerly of those lying wholly within the arid region. In spite of the general lack of moisture, there are a few areas among the mountains where crops have been raised by dry farming, but as a rule irrigation is essential to successful agriculture.

The Great Plains, which extend across Kansas and Nebraska and into eastern Colorado, sweep northerly and westerly around the Black Hills and Bighorn Mountains. Contrary to popular concep-

CANYON OF SNAKE RIVER ABOVE LEWISTON, IDAHO.

tions, the altitude descends toward the north, the country being lower in northern Montana than in eastern Colorado. This fact is emphasized because of the commonly expressed opinion that water might be diverted from Missouri River and carried out southerly along the upper edge of the Great Plains, furnishing an abundant supply for this vast area. It is, however, impracticable to divert the Missouri River to cover any considerable portion of these dry lands.

Montana, like Colorado, extends from the Great Plains westerly across the Continental Divide, fully two-thirds of the state consisting of rolling lands and plateaus broken by occasional mountain masses. Here the water supply is scanty, although this part of the state is traversed by two large rivers — on the south by the Yellowstone, and on the north by the Missouri, these uniting at the eastern border. The western third of the state is mountainous and comparatively well-watered, these high mountain masses furnishing perennial streams, necessary to the utilization of the low-lying valleys with fertile soil and genial climate. The great problems of the development of Montana relate to the possibilities of obtaining water for the vast extent of great plains away from the mountains.

The ease with which water could be brought upon land and the presence of a market at the mines within the mountains have caused western Montana to be the most thickly populated and

well-cultivated part of the state, while the great eastern plain or prairie region, with its almost boündless extent of rich soil and its great rivers, the Missouri and Yellowstone, is almost unsettled.

The most important agricultural area is in Gallatin Valley, of which Bozeman is the principal town. Here alfalfa and cereals are raised, barley especially being of superior excellence and value. East of this, and along the Yellowstone River, in the vicinity of Billings and other towns, are numerous areas under cultivation. Northerly from these localities and extending across the state are various points where irrigation has been introduced, especially in connection with stock raising, water being taken principally from the smaller streams which can be readily controlled.

Along Milk River, which flows from the northwest into Missouri River, settlement has progressed rapidly and irrigation has been attempted, but the supply of water is far below the demands. To remedy this condition, surveys have been made to ascertain the practicability of diverting the water from Saint Mary River, which receives the drainage of a part of the snow-clad Rocky Mountains, and flows northerly into Canada, being separated from Milk River by low gravel ridges of glacial origin. It has been found possible to bring a large canal through these ridges, restoring to its eastern course the water which, until prevented by glacial deposits, presumably flowed easterly across the plains.

Mining is the principal industry of the state, this being confined to the mountains in the western end. Next to this in importance is stock raising; the greater part of the state is devoted to this business, the great herds of cattle fattening on the open public land for the Eastern market. Irrigation has been carried on largely as an adjunct to the cattle business, in order to furnish hay for the winter feed. Proper control of the free grazing is one of the great problems now presented.

The importance of irrigation is steadily increasing as settlers push in, and the open ranges are being more and more crowded with cattle, horses, and sheep. The resulting overgrazing necessitates occasional feeding, especially in winter, and this in turn calls for an increase of irrigated area, in order that hay and particularly alfalfa may be produced. The necessity of winter feeding and the greater labor thus involved tend to reduce the large herds, as noted on p. 40, and to increase the number of small ranches, whose owners can give personal attention to their cattle grazing on the surrounding lands.

NEVADA.

Nevada, although of great extent, enjoys the unenviable reputation of being, in population, the smallest state in the Union, and of having decreased rapidly in this respect. The number of persons in 1890, about 45,000, has in ten years diminished to a little over 42,000, there being fewer people than

in Alaska or in any of the seven territories now under the control of the United States. The decrease in population has resulted mainly from the lessened output of the mines and neglect to make use of the agricultural possibilities.

The total land surface of the state is 109,740 square miles, almost exactly that of Italy, which has a population 750 times as great. In 1900 there were irrigated 510,000 acres, most of this being devoted to raising hay. A considerable portion of this half-million acres is made up of lands partly overflowed by the Humboldt and other rivers, the flooding being assisted in a relatively small degree by ditches and by dams placed in the stream. In point of cost and value, such irrigation is by no means comparable to that practised in many other states, being little more than an attempt at assisting nature in spreading water over the surface during spring floods.

The state lies almost wholly within the Great Basin, a region from which no streams escape to the sea. The rivers, flowing from lofty mountains, continue out upon broad valleys, and their waters are finally lost in extensive marshes or open lakes, the evaporation from the surface balancing the inflow. In former geologic ages, when the rainfall was presumably greater, these valleys were occupied by large bodies of fresh water, which discharged probably toward the north, increasing the flow of Columbia River. The Great Basin

extends easterly beyond the boundaries of Nevada and includes a large part of the state of Utah.

On the western border of the state are the high mountains, the Sierra Nevada, which are almost wholly within the state of California, the boundary line being drawn along the eastern slope below the main summits. These mountains fend off the moisture coming from the Pacific Ocean, and as a result the state of Nevada is as a whole the driest of all the arid states. High mountain masses irregularly distributed over the Great Basin break up the surface, and from these flow small streams, the larger uniting to form the Humboldt River, which crosses the northern end of the state from east to west. The other important rivers are the Truckee, Carson, and Walker, which flow westerly from the Sierra Nevada.

Because of the extreme dryness of the country, the sections numbered 16 and 36, which in other states were devoted to educational purposes, have been in the case of Nevada left in the hands of the government, and in their stead a grant of 2,000,000 acres of public land has been made to the state. Most of this has been selected by cattle companies, lands being chosen in such a way as to include nearly all of the springs and smaller sources of water. Thus the cattlemen have been enabled to control practically the entire agricultural area through the ownership of the water, and settlement has been retarded.

The problem of transportation has also been one of fundamental importance to Nevada. There is only one main line of railroad, the Central Pacific, controlled by the Southern Pacific Company. The managers of this line have in the past apparently regarded the space between Utah and California as a great unavoidable gap to be bridged, and the development of population in this space has been practically accidental as far as the railroad is concerned. Few, if any, efforts have been made to facilitate settlement, and local traffic rates have been almost prohibitory. Thus it results that the natural aridity, preventing dry farming, the aggressions of the cattlemen, making settlement almost perilous, and the unfavorable attitude of the railroad, adding to the cost of home building, have deterred settlers and left the state to consist mainly of the remnants of a mining population.

The Truckee, Carson, and Walker rivers, flowing from the Sierra Nevada in California easterly into the valleys of Nevada, furnish by far the greater part of the water supply for the state. In the relatively small area along these rivers, adjacent to the California boundary, are the principal towns and most of the people. Scattered along Humboldt River, crossing the northern end of the state, are a number of small settlements, a few outlying mining camps being found farther south. Stock ranches for headquarters and supply places for the sheep and cattlemen are located at remote

points near springs, or at the mouths of canyons from which water issues upon valley land. Here small areas are irrigated, mainly for winter forage.

The development of the state will be possible by constructing reservoirs on the tributaries of Humboldt River, and even on the main stream, and particularly on the head waters of the rivers flowing from California. Interstate problems are involved in the latter undertaking, but surveys have demonstrated that works can be built at feasible cost to reclaim many thousand acres, making possible homestead settlement on the lands now valueless. The reservoir which has attracted the greatest amount of public attention is Lake Tahoe, at the head of Truckee River, and it has been shown that by holding its waters back by means of a suitable dam, water can be retained for the irrigation of thousands of acres.

In addition to the reservoir sites occupied in part by lakes and to which public attention has been especially drawn, there are broad valleys in which artesian water can possibly be had, and also many localities scattered through the mountains suitable for holding water. These are mainly small valleys, in some cases formerly occupied by glaciers, and later by lakes, which in course of time have cut an outlet through the lower rims. A comparatively small expenditure of labor and capital will close the outlets, and by this means bodies of water of considerable size can be held.

The rain and snow fall on these high mountains aggregates from 30 to 40 inches or more annually, this being sufficient to replenish the reservoirs if constructed.

NEW MEXICO.

New Mexico, although well within the arid region, presents many contrasts to Nevada. This results largely from the difference in population, and the way in which lands have been held and agriculture has been practised. The population of the state consists largely of Mexicans, and the cultivation of the soil is almost wholly in their hands. The territorial form of government still prevails, although the population, 195,310 in 1900, surpasses that of the states of Delaware, Idaho, Nevada, and Wyoming. The territory is three times the size of Ohio and has less than a twentieth of the population.

The oldest irrigation works in the United States are in this territory, having been built by the Pueblo Indians or their Mexican neighbors. The average size of an irrigated farm is small, the lands under ditch having been subdivided among the sons of the family instead of additional areas being brought under cultivation. The farmers, especially those of mixed Spanish and Indian descent, have followed the customs of their fathers, and show little energy or skill. The lands are tilled in a most laborious fashion, largely by hand, and the returns are small.

The eastern part of the territory has been, until recent times, the paradise of cattlemen and of outlaws, many of whom have taken temporary service in the retinue of one or another of the great cattle kings, and have alternated the business of "rounding up" cattle with that of keeping out settlers or evading the officers of the law. Within recent times, however, much of the lawlessness has been broken up, particularly since the introduction of irrigation along Pecos River, the advent of farmers, and the extension of railroads from the East and the South.

The Rio Grande, rising in southern Colorado, enters the territory from the north through deep canyons. These widen in places, allowing room for bottom lands, and again the walls die down, forming low mesas. The proportion of open land increases toward the south, and here are the principal towns and agricultural communities. The river itself tends to spread out over the bottom lands, and the greater part of its water gradually disappears by evaporation or by diversion into ditches, so that in the lower part of its course, above El Paso, Texas, the stream channel is frequently dry. There are very few large canals, but a great number of small community ditches supply lands held by the Indians and Mexicans. The origin of these ditches is lost even in local tradition, and it is probable that many of them were in use before the advent of white men. The

waters of the river are extremely muddy, especially after spring rains, and the sediment, carried in suspension, fills the ditches, necessitating frequent cleaning, especially of those having slight grade.

The development of the resources of New Mexico rests largely upon the control of the Rio Grande. On the head waters of this stream, in Colorado, are a number of large canals, the capacity of these being sufficient to take all of the river at that point. The seepage and inflow from small streams maintain the river at a moderate volume in northern New Mexico, but practically no water penetrates to the southern end of the territory during the irrigation season. There are a number of open valleys along the course of the Rio Grande and on its principal tributaries, where by building large dams great quantities of water can be held. Several of these localities have been surveyed.

The principal storage project is that above El Paso, where it has been proposed to construct a great international dam to regulate the flow of the Rio Grande where it forms the boundary between the state of Texas and the republic of Mexico. The periodical drying of the river and the shifting which takes place during occasional floods make the boundary a matter of great uncertainty, and result in continual irritation between the authorities on both sides.

There are few notable irrigation works along the Rio Grande, the ditches for the most part being

small and having temporary dams of brush and stone. These are swept away in time of flood and must be replaced after the spring freshets. The ditches do not, as a rule, extend beyond the lower land, and the terraces or mesas along the stream, usually having better soil, are not as yet cultivated. A considerable portion of the bottom land is alkaline, and many small farms have been abandoned and even towns deserted because of the accumulation of earthy salts. Drainage is in many localities almost as necessary as irrigation.

The typical Mexican farms consist of long, narrow strips extending from the foothills to the river and crossed by a ditch. The peculiar shape of these farms is due to the fact that, in dividing the inheritance, it is customary to give each heir an equal amount of the hill land and the frontage on the ditch and river; the result is that these tracts may be from 25 to 300 yards in width on the stream and a thousand or more yards long, extending up the slope to the ditch or beyond it to the hills. This causes much inconvenience in cultivating, and is accompanied by lack of economy in irrigating.

The ditches, as a rule, are owned in common by the farmers of each community, and one of the irrigators is annually elected superintendent, or majordomo. His business is to attend to all necessary repairs, regulate the distribution of water, largely according to his own judgment and experience, and in case of extensive work call upon all

of the farmers to contribute each his share of labor.

The largest irrigation system is that on Pecos River, in the southeastern part of the state, supplying land in the vicinity of Carlsbad, formerly known as Eddy. Here dams have been built across Pecos River, forming reservoirs, the largest of which is known as Lake McMillan. From the latter a canal extends along the river, branching to cover lands on both sides of the stream.

OREGON.

The western portion of Oregon, bordering on the Pacific Ocean, is humid. The belt of well-watered land extends easterly to the Cascade Range, which forms a barrier to the progress of the moist winds on their journey inland. About two-thirds of the state is on the eastern or dry side of the mountains, and in this portion irrigation is necessary for most crops, although wheat, barley, and rye are successfully cultivated by dry farming on the uplands around the Blue Mountains and near the Columbia River.

The country east of the Cascade Mountains may be pictured as a series of broad plains and mesas, covered with lava of various ages, from that outpoured recently to the ancient flows whose surface has largely changed into soil. This supports a dense growth of sage brush, and also juniper near the mountains, these being intermingled with for-

age plants. The vegetation becomes sparse out on the broad valleys, but nearly everywhere furnishes good grazing.

The erupted material forming the plains is similar in many respects to the vast sheets of lava or basalt covering the valleys of southern Idaho. These lavas occur around the Blue Mountains, and are apparently continuous from southern Idaho to the Great Bend country of the Columbia in central Washington. Volcanic cones rise from these plains, and the general level is interrupted in places by mountain masses whose lower portions have apparently been buried by the outpouring of fluid rocks. The altitude of this land is from 3000 to 4000 feet, the mountains rising to 8000 feet or over. The most important of these are the Blue Mountains, in the northeastern part of the state, which consist largely of extremely steep, rugged peaks, snow-capped for a considerable part of the year. The foothills of these mountains, at altitudes of from 5000 to 7000 feet and over, are covered with timber, much of it being pine of considerable value. From these highlands come the streams important in irrigation development.

Water storage is highly essential for the growth of agriculture in central Oregon. The streams are small and intermittent in character. Reservoir sites are known to exist on them, but none have been surveyed. Crooked River, which receives its supply from the Blue Mountains, is typical. It

has spring floods, which rapidly subside toward summer, until the channel of the stream is nearly dry. By building dams at a number of localities along its course it is probable that the summer flow can be increased to an extent sufficient to irrigate many thousand acres.

Similar to this is Silvies River, which flows out upon the northern edge of the Harney plain or desert. Where this stream leaves the canyon it has built a broad delta, through which the water meanders in a number of channels. Much of the ground is overflowed during the spring flood, and considerable areas, originally marshy, have been utilized as hay lands by slightly regulating the flow of the stream and by annually cutting the native grasses and weeds. The quality and quantity of these are greatly improved by this regular treatment. The area of valuable hay land has been increased by check dams placed in the diverging channels, causing the floods to spread on the low lands. The cultivation of more valuable crops can be made feasible by enlarging the canals from Silvies River, and especially by insuring ample water for summer through the construction of storage works. The same thing is true to a greater or less degree of the various tributaries of Malheur River and other streams issuing from the Blue Mountains.

Where a sufficient supply cannot be had from surface streams, it may be practicable to obtain

water from underground, particularly from artesian wells sunk in the broad desert valleys. The structure of some of these is known to be favorable to the accumulation of water, and it is highly important to make a thorough geologic examination, if necessary by the drilling of one or two wells of such depth as to penetrate the recent deposits and definitely determine whether flowing water can be had. By so doing maps can be prepared showing the depth to the water-bearing horizon and the probable height to which the water will rise. This is true of the broad valleys of central Washington, as well as of the Harney and Malheur valleys of Oregon. The soil of these is very fertile, and in many places the forage plants furnish good grazing; but the distance from springs or streams is so great that cattle cannot graze except during the winter season, when pools of water are occasionally formed. If a supply could be had from deep wells, the cattle and sheep industry would be greatly benefited and it is possible that considerable areas might be irrigated. With improved transportation facilities there will be opportunities for making many farms on the vacant land of central Oregon.

UTAH.

This state, occupying the central portion of the arid region, has led in the development of irrigation by associations of farmers tilling small areas.

The average size of an irrigated farm is less than in any other part of the country, and consequently the number of persons supported per acre is greatest. This has been due to the peculiar system of organization growing out of Mormon practices. The excellent results attained demonstrate the practicability of industrious pioneers supporting themselves and attaining prosperous homes on small tracts.

The land surface of the state has an area of 82,190 square miles — over ten times the size of Massachusetts — and the population in 1900 was 276,749, or one-tenth that of the latter state. The principal part of the population is on the narrow strip of land at the foot of the mountains east of Great Salt Lake and of the smaller body of fresh water, Utah Lake. Agriculture is dependent upon irrigation, except in the case of wheat and barley, which are raised by dry farming on some of the higher bench lands. In localities where snow covers the ground, it has been found possible, by summer fallowing and by planting hardy varieties of cereals in the fall, to obtain a good crop; and with skill gained by experience the area thus planted is being extended. For alfalfa and other forage plants, and for general farm crops, as well as for orchards, irrigation is essential.

The water supply of the state is relatively well distributed in a number of creeks and small rivers issuing from the Wasatch Range. These moun

TUNNEL OF BEAR RIVER CANAL, UTAH.

tains rise abruptly from broad valleys, and receive upon the summits a considerable amount of rain and snow. The streams have cut deep canyons, and as they issue upon the plains their waters are diverted by many canals and ditches. Nearly all of these have been built by associations of farmers living in small communities on the bench land near the mouths of the canyons. There are very few large structures built by capital obtained outside the state, and, so far as can be ascertained, all investments of this character have been financially unsuccessful. On the other hand, the farmers, uniting in associations and furnishing their own labor and teams, have built works, some of them of considerable magnitude, and through the use of these have increased the value of their property to such an extent as to make the investment highly remunerative. It is to be noted, however, that it is the owner and tiller of the soil who has become prosperous, and not the owner of the irrigating system. One of the largest works in the state is the Bear River Canal, a portion of which is shown on Pl. LV.

Growing out of the complete church organization of the people have come methods of allotting and distributing water which have proved sufficient for most localities. Controversies occasionally arise, but these are usually settled by what amounts to a majority vote of those concerned. There is an attempt made to divide water by priority of

time at which it was put to beneficial use, but the strict regard to priorities has often been set aside in favor of a more equitable distribution during times of scarcity. In other words, priorities have been disregarded in favor of needs of men owning orchards which would be destroyed if water could not be had, temporarily at least. There is also put in practice a grouping of rights as described on p. 293.

The Bear, Ogden, and Weber rivers are the principal streams of the western part of the state, and receive a considerable part of the drainage of the Wasatch Mountains. The most notable river, however, is the Jordan, which flows into Great Salt Lake from the south, being the outlet of Utah Lake. The latter body of water lies at an elevation considerably above Great Salt Lake, so much so that its waters are taken out by canals covering the valley lands and extending to the city of Salt Lake.

Utah Lake receives from the east a number of large streams, the most important of which is Provo River. The ordinary flow of this and other streams is fully utilized during the summer, and extension of irrigation is dependent upon water storage, for which there are a number of favorable sites in the mountains. One of the most important developments for the state is the complete regulation of these head-water streams by the construction of impounding dams and the control of Utah

Lake, by which its waters may he drained down to a small extent and the lake made available to the greatest possible capacity for lands in Salt Lake Valley.

At about the centre of the state is Sevier River, which flows from the high plateaus and mountains of the southern part of the state northerly toward Utah Lake, but, before reaching it, turns abruptly to the west, its waters finally disappearing in a marsh or sink, known as Sevier Lake. A number of important towns and farming communities are located in the valleys along this river, and the water is as fully used as can be without storage. Excellent opportunities exist for conserving water, and on some of the tributary streams small reservoirs have already been built by the farmers.

The eastern side of the state is drained by Colorado River and its tributaries, the largest of which is the Green. Near the head waters these streams are used to a small extent on the lands of the elevated plateaus and of the small valleys intersecting them, but the general character of this drainage is typified by the Colorado, which flows in a deep, narrow canyon without any bottom land. The greater part of the water is thus lost to agriculture, although it may be of industrial value in the future as a source of power. If any of it is to be used for irrigation, this can be accomplished only by storage and diversion near the head waters, before the streams have cut down into the solid rocks.

This river escapes to the Pacific Ocean through the Gulf of California, but, with the exception of this drainage area, the state of Utah lies wholly within the Great Basin.

The western side of Utah consists of broad, arid valleys interrupted by sharp mountain ranges, and has the desert aspect which characterizes the Great Basin. There is some timber upon the mountains, and also grazing, but the valleys are, for the most part, barren, supporting only a growth of sage brush and similar plants. The difficulty of obtaining water, even for cattle, has prevented the settlement of this country, although prospectors and miners have made temporary homes and camps, some of them important. Artesian waters are found in many parts of the state, especially in the vicinity of Utah Lake and Great Salt Lake. It is possible that deep wells can be successfully sunk in some of the desert valleys.

WASHINGTON.

The western portion of the state of Washington, especially in the region of Puget Sound, is noted for its fogs and heavy rainfall. East of the Cascade Range, however, as in Oregon, the country is extremely dry, except near the Canadian border and among the foothills adjacent to northern Idaho. Throughout eastern Washington, on the rolling uplands, and southerly across Columbia River and around the flank of the Blue Mountains,

WHEAT FIELDS OF WASHINGTON.

is a country which, though possessing a distinctly arid climate, has been found to be one of the best-known areas for raising wheat. The soil, resulting from the decay of basalts and lavas, is extremely rich, and, although almost ashy in texture, has the peculiar property of retaining and transmitting to the plants a sufficient amount of water to insure luxuriant growth. Broad wheat fields, shown on Pl. LVI, extend in every direction as far as the eye can reach, covering a land which has been considered worthless except for grazing. The water supply is very scanty, barely sufficient for domestic purposes. The rivers, like the Columbia and its principal tributaries, flow in deep, narrow canyons, and although the volume of water is large, it is impracticable to bring any of it to the tops of the adjoining cliffs upon which the farms are located.

In the valleys immediately east of the Cascade Mountains irrigation is practised, especially along Yakima River, which receives the waters of the melting snows on high mountains. It flows through a number of valleys in succession, and many small ditches divert water, also a few large canals, the most important of which is known as the Sunnyside Canal (Pl. LVII, *A*), irrigating land below Yakima. The principal crop produced, besides alfalfa and fruits, is hops, the climate being found peculiarly favorable for these.

Columbia River, which flows through the state from Canada, and Snake River, its principal tribu-

tary, are in deep, narrow canyons through the greater part of their courses. Along their banks are many wheels designed to lift water by means of buckets placed upon the rim, as shown on Pl. XLI. These make possible the cultivation of small fruit farms on the narrow strip of land between the river and the foot of the cliffs. These little farms, being sheltered from the wind, and receiving sunshine and warmth, produce fruit of high quality, such as peaches, pears, prunes, and other varieties of plums. These are transported, mainly by water, to the local markets at Portland and elsewhere.

The interior of Washington is in many respects similar to that of Oregon, particularly in what is known as the Great Bend country. Here the streams are small, not having a mountainous catchment area; but it is believed that water conservation is practicable on some of the coulées, as well as on the Palouse River, which flows from the highlands in the eastern part of the state, and on the Pataha, Wallawalla, and similar rivers coming from the Blue Mountains, making possible the reclamation of extensive areas of vacant land. Artesian wells have been sunk in some of the valleys, particularly near Pullman, on the eastern side of the state, and in the Moxee Valley, east of Yakima River. Water-bearing gravels have been found beneath or interbedded with the lava flows. An ideal section of these artesian conditions is given in Fig. 93, prepared by Professor Israel C. Russell.

The mountains in the background are intended to represent the far side of a lava-floored valley. Sands and gravels derived from the mountains have been washed into the valley, and from time to time flows of lava have taken place. A well

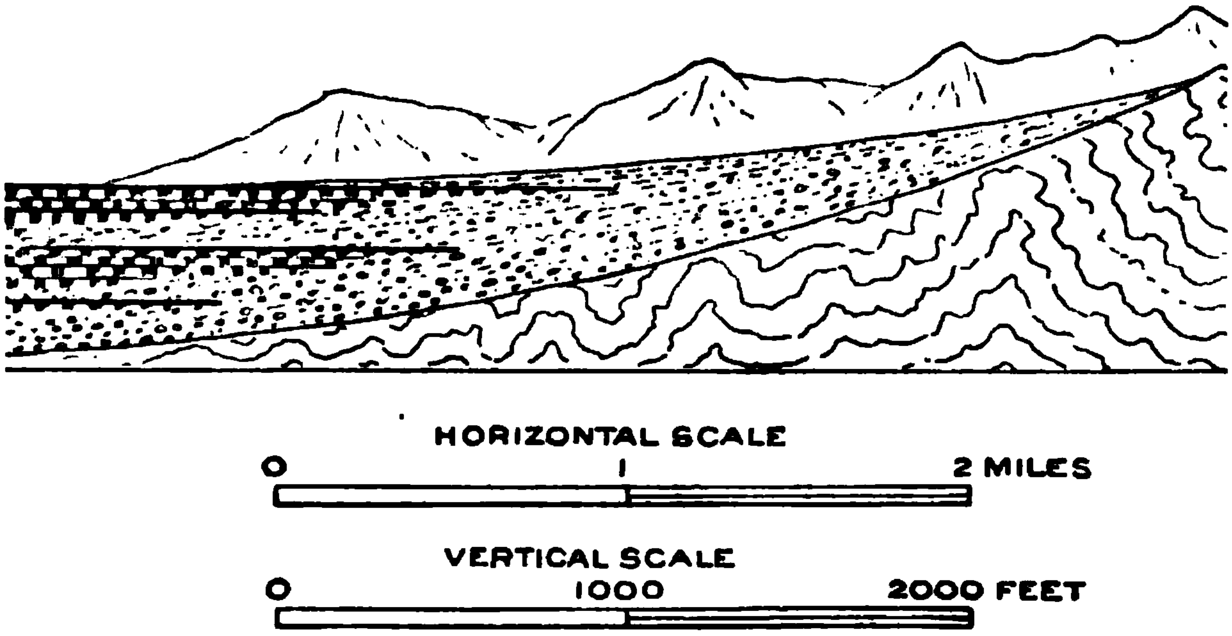


FIG. 94. — Ideal section of the border of the Columbia River lava adjacent to the mountains.

drilled through these lava sheets, until a porous water-charged bed is reached, will yield a surface flow, provided the mouth of the well is below the exposed portion of the pervious layer, and also provided that there is an unbroken impervious bed both above and below it, as described on page 248.

WYOMING.

This state, because of its high altitude, cool climate, and broad, almost desert plains, is and probably always will be devoted mainly to the grazing industry. Mining is of considerable importance, but agriculture is relatively unimportant.

The altitude of Cheyenne, the capital city, is a little over 6000 feet. This is located on the edge of the high plains, near the foot of the Laramie Hills. From here the plains continue northward between the Black Hills on the eastern edge of the state and the Bighorn Mountains near the centre of the northern part. There is a gradual decline in altitude toward the north, the town of Sheridan having an altitude of about 3700 feet. Here agriculture by irrigation has been most largely developed. In the Bighorn basin, west of the mountains, the altitude is also relatively low, 5000 feet or less, and the water supply large, so that opportunity for the increase of farms is good.

The area of the land surface of the state is 97,575 square miles, or 62,448,000 acres. The population in 1900 was only 92,531, being a little less than one per square mile. The average size of the irrigated holdings is large, since most of these consist of hay farms operated in connection with cattle ranches. The cost of water is correspondingly small, as developments have consisted mainly of ditches for bringing water out upon meadows. The water supply of the state, for an arid region, is not only relatively large, but is well distributed, the principal rivers being the North Platte and its tributary, Sweetwater River, receiving the drainage of the southeastern part of the state, Powder River, on the east side of the Bighorn Mountains, and the Bighorn, on the west side

A. SUNNYSIDE CANAL, WASHINGTON

B. FRUIT ORCHARD, YAKIMA VALLEY, WASHINGTON.

of the same range, also Green River in the southwest corner. Some of these are of such size that there is little probability that the waters will ever be seriously diminished by irrigation; but on the east side of the Bighorn Range, in the vicinity of Buffalo and Sheridan, there is already demand for water storage.

One of the most important irrigation systems of the state is that in the vicinity of Wheatland, north of Cheyenne. Water is obtained by a tunnel through the Laramie Range, being brought from Laramie River to the east front of these mountains, where it is distributed by a number of canals. The ordinary flow of the river is increased by a storage reservoir built above the mouth of the tunnel, and the available supply is further regulated by storage works in the vicinity of the irrigated land.

CHAPTER XII.

STATES OF THE SEMIARID REGION.

THE location of the semiarid region has been shown in Fig. 2 (page 14), and a definition has been given of the location of the area. There are also in western Oregon and Washington narrow belts which may be designated semiarid; but the transition between arid and humid conditions in those states is so quickly made that these regions are not generally recognized.

There has been no careful distinction made between the use of the words "semiarid" and "subhumid," and they are considered as practically synonymous, since both are relative, the term "semiarid" implying a little drier condition than "subhumid." As shown on the map (Fig. 2), the semiarid region extends in a broad belt across the United States, in a general northerly and southerly direction, and is included mainly within the states of North Dakota and South Dakota, Nebraska, Kansas, Texas, and the Territory of Oklahoma.

FLUCTUATIONS IN WATER SUPPLY.

The broad belt east of the arid region and forming the debatable ground between it and the humid

lands of the Mississippi Valley presents conditions so nearly uniform that it may be considered as a geographic unit. No definite boundaries can be assigned, because of the fact that for a number of years in succession summer rains may be above the average and the vegetation will be luxuriant, so that in driving across this land it seems to be a perfect flower garden and a paradise for cattle; while again the rainfall may be deficient year after year, vegetation become parched and almost disappear, and the traveller will apply to it the old term, the "Great American Desert." Thus it has happened that one or another of the early pioneers has spoken in glowing terms of the fertility and beauty of these high plains, and others with equal sincerity have described the horrors of the long, thirsty drives across the sterile wastes.

The alternations in the amount of moisture are best marked by small, shallow lakes which sometimes dot the plains, especially toward the north. After a cycle of wet years these are found scattered here and there; but they disappear again, and leave no trace of their existence except by muddy flats or stretches of hard-baked adobe. Another way of describing the conditions is to say that the arid conditions at times creep down the slopes of the high plains and extend far eastward, and again retreat to the base of the Rocky Mountains, swinging backward and forward without any known rule or regularity. As the soil is

very fertile, there is constant temptation for the settler to push westward from the humid East during seasons of abundant rainfall, with the result that after he has begun to make a home he is overtaken by the reverse swing of climatic conditions, and suffers from successive droughts. These usually force him to abandon his farm and improvements, through continual loss of crops.

This peculiar condition of rich soil and fickle rainfall is common to all regions of the globe where great famines have occurred. The extreme productiveness of the soil after a heavy rain encourages an extension of agriculture and a general lack of thrift, so that often when the crops do fail population has increased rapidly and little provision has been made for meeting continued losses. In the popular mind nearly every probable and improbable cause has been assigned for this change of climatic conditions, and with limited range of observation it has sometimes been assumed that the rainfall is continuously increasing or diminishing. By selecting periods of five or even ten years it has been possible to support either theory.

It has been for the interest of speculators in land and of transportation companies to adopt the theory of gradual increase of available moisture on the Great Plains, and the results attained from about 1880 to 1886 seemed to support the conclusions. It was asserted that the rainfall was increasing as settlement advanced westward, or, in other

words, that rain came with the breaking of the sod, the building of railroads, telegraph lines, and other works. The people who adopted this theory were locally known as "rain-belters." They showed their confidence in the theory by taking up land in advance of permanent settlement, far out on the plains, confidently believing that the rain-belt would reach them before long. They were disappointed, however, and as year after year rolled by without perceptible increase in moisture, and with continually recurring losses of crops, they became discouraged or literally starved out. The homes of some of the rain-belters are shown on Pls. I, III, and LIX, *A*.

There has been a succession of waves of settlement following years of unusual rainfall, and time and again men have pushed forward, getting a foothold and raising one or two crops, and then dropping back. This is shown by the statistics of population of western Kansas, the numbers rising and falling through series of years.

One of the results of climatic oscillation in the subhumid region, and of the ruin wrought by lack of knowledge of the facts, was the speculation in Western mortgages, which affected not merely the plains region, but also citizens resident in all parts of New England and the East. As the rain-belters marched triumphantly westward, they found that their movements were facilitated by companies formed to place loans and take mortgages on real

estate. The profits of these loan agencies became so great that large numbers of them were formed, and competition for business became so keen that ordinary prudence was thrown aside, and the settler no longer sought for a person to make small advances of capital by which he could procure tools and seeds. No sooner had he located than rival agents hunted him up, to bid against one another for the privilege of placing a mortgage upon his farm. These mortgages, being for a few hundred dollars, were then peddled out to small investors throughout the country, being purchased by schoolteachers, clerks, and mechanics, who had laid up a small amount of money and were seeking the largest possible interest.

Although the crop from one of these farms would, in a year of abundant rainfall, pay off the mortgage, this was not done, because of the desire of the settler to purchase more farm implements or obtain additional land; and when a series of dry years came and no crops were had season after season, the landowner, appreciating that the mortgage and interest amounted to more than the farm was worth, simply abandoned everything, and thus whole counties were practically deserted; about the only inducement to maintain the county organization being the fees obtained by the officials in connection with the mortgage business. This business has continued because of the fact that Eastern mortgagees, not knowing the true condi-

tions, have often foreclosed, or transferred their interest, or continued to pay taxes in the vain hope that the land may some time be worth what has been loaned.

It should not be assumed that every one has left the subhumid region; on the contrary, among those who have tried their fortunes there are some who have clung with great tenacity, and who have been able to adapt themselves and their methods of farming to the conditions. They have introduced irrigation, as shown on Pls. II. and IV., or have practised tilling of the soil in such a way as to conserve the moisture, and have usually been able to cut and stack sufficient hay to maintain their cattle throughout the short winter. The vacant public lands and the abandoned holdings about them have furnished ample grazing for small herds, and by planting sorghum and hardy varieties of small grains they have been sure of a fair return for their labor. When the years of abundant rainfall occurred, they have sometimes been able to secure a large crop of wheat, or even corn, whose value has reimbursed them for all of the previous outlay.

These sturdy pioneers have sometimes displayed great ingenuity in utilizing the resources about them; such, for example, as seen in the construction of homemade windmills, shown on Pl. XLII and described on page 266. By means of these mills water has been pumped to the surface and

held in small reservoirs, or dams have been built across ravines, impounding storm waters. The experiments and success attained have shown that it is possible for farmers of a high order of intelligence and perseverance, not only to make a living, but even to secure a competence, in this region of uncertain rainfall.

Although it is now well known that the amount of rainfall cannot be influenced by human agencies, yet it is possible to greatly increase the available supply for plant life by storing the water in the soil through careful cultivation and by preventing evaporation losses through planting wind breaks. It is estimated that every foot of height of compact trees protects 1 rod of ground; hence a Lombardy poplar wind break of an average height of 60 feet, properly set out, has a beneficial influence extending practically 1000 feet to the leeward. For these breaks poplars, cottonwoods, or locusts are serviceable. By practising all these economies, shutting off the wind as much as possible from the fields and using it for pumping water, storing the scanty supply in reservoirs or in the soil itself, the observing, careful farmer wins success where others fail.

For convenience the boundary of the subhumid or semiarid region has been placed on the east at the 97th meridian and on the west at about the 101st. It is a region of extremely fertile soil, the erratic rainfall being followed by rapid growth of

A. IRRIGATION IN SOUTH DAKOTA BY USE OF WATER FROM AN ARTESIAN WELL.

B. STOCK-WATERING PLANT ON UPLAND.

grasses and other plants valuable for forage. The ground is almost everywhere covered with a tough sod (Pl. LXII), which thins out toward the arid region, gradually breaking into small patches and finally forming what is known as bunch grass, each tuft being surrounded by bare soil.

The water supply of this region is for the most part concentrated in a few rivers, from which irrigation canals can be taken. The principal exception to this is the Missouri River, which flows across the northern end of the subhumid belt. The fall of this stream is so slight that it is impracticable to divert water by gravity. Some of it may be had by pumping, but the increase in value of the bottom lands would not be sufficient to justify the expense, as many of these are kept moist by seepage. The bench lands, having in general a better soil, cannot be reached by a canal from the Missouri River.

Southward from the Missouri, in North Dakota, the principal rivers are its tributaries in South Dakota, also the Platte in Nebraska, the Republican, Smoky Hill, and Arkansas in Kansas, and the Canadian in Texas and Oklahoma. The Platte and Arkansas have cut their way entirely across the subhumid region and receive the drainage from the Rocky Mountains. Some of this water succeeds in finding its way from the mountains to the Mississippi River, but during the summer the entire supply is needed for lands

within the arid region, and for several hundred miles these streams are nearly or quite dry. Extensive irrigation systems have been built in western Kansas, notably in the vicinity of Garden; but the chances of obtaining water are so precarious that the owners of the canals have become discouraged, and neglect to keep them in repair.

During the time of abundant rainfall irrigating ditches in the subhumid region fall into disuse, and the irrigator, for lack of practice, becomes indifferent. As a result, when the rains no longer come, and day after day passes without relief, and attention is drawn to the necessity of irrigation, it is usually found that, even if there is water in the river, there are a number of repairs to be made to the canals and the flumes are leaking or defective; and, in short, before water can be brought to the field the crop has already been greatly injured or destroyed. It is extremely difficult for a community raising an occasional good crop without irrigation to maintain the necessary works and expend labor in repairs when there is no immediate necessity for an outlay, and when optimistic members of the community claim that the rainfall is increasing and irrigation ditches are no longer needed.

There is a strong opposition to letting the fact be known that a certain region needs irrigation. The short-sighted policy is practised of attempting to conceal the deficiencies of climate from the

would-be purchasers or investors, and, instead of regarding the possibilities of irrigation in the light of an insurance to the crops, it is considered as a burden to be avoided. This is due to the fact that most of the newcomers in the semiarid region have practised farming in humid localities, and, not having had experience in irrigation, are afraid or suspicious of any proposition necessitating the artificial application of water to the soil; thus the attempt is sometimes made to discourage any movement in favor of irrigation construction, for fear of frightening away the men who are seeking homes. As the public becomes better enlightened upon the subject, it will come to be generally known and acknowledged that irrigation greatly benefits a locality.

ARTESIAN AND DEEP WELLS.

The streams which cross the semiarid region flow in a general easterly direction, and occupy narrow valleys trenched in the plains. A traveller driving across country in a northerly or southerly direction finds a rapid alternation of plain and ravine; but if he is going east or west on the flat uplands between the streams, the country will appear to his eye as perfectly level, the narrow valleys not being visible. Out on these broad expanses, unscarred by running water, are the best soils, surpassing even those of the bottom lands. For these areas the problem of water supply is

serious, and it is often impossible to find any feasible relief from drought. In many localities, however, wells having a depth of from 100 to 300 feet, as shown on Pl. LVIII, *B*, obtain an ample supply, and in other places artesian conditions have been found to exist, water flowing over the surface in a quantity sufficient not only for stock, but even for the irrigation of small farms, as shown on Pl. LVIII, *A*.

The principal developed artesian area is in the James River Valley of South Dakota. Here are a considerable number of wells ranging in depth from 1200 to 1500 feet, some of them, as shown on Pl. XL, discharging volumes of water of one cubic foot per second, or even more, as described under the head of Artesian Wells, p. 246. These receive water from what is known as the Dakota sandstone, a thick rock, sometimes merging into shale, but usually consisting of coarse, permeable sandstone. It outcrops around the Black Hills and along the front of the Rocky Mountains, and extends easterly under the plains at depths of from 1000 to 2000 feet or more, as shown in Figs. 79 and 80 (p. 250), approaching the surface in the eastern part of Kansas, Nebraska, and the Dakotas. It outcrops along the Arkansas Valley and appears on the surface near Coolidge in western Kansas. Wherever penetrated, it yields an abundant supply of good water, although at a few places it is reported that the water is con-

A SETTLER TRYING TO CULTIVATE WITHOUT IRRIGATION

B WATER FOR IRRIGATION PROVIDED BY WINDMILL.

taminated by salt, probably from some other horizon.

The position and depth of the Dakota sandstone have been mapped around its edges, but in the centre of the plains region the depth beneath the surface to the sandstone is unknown. It is highly desirable to drill one or two deep wells, determining the depth, character, and thickness of the Dakota sandstone, and ascertaining whether it or other sandstones contain water under sufficient pressure to rise to the general level of the country. It is possible that, by the complete development of artesian wells, the opportunities for making homes can be greatly increased.

Wherever wells have been dug or drilled in this area it is the custom to erect windmills, as shown on Pl. LIX, *B*. A great number of these have been built, as the wind is blowing almost continually, with a force sufficient to operate ordinary pumps. Many thousands of them are to be seen, of all forms and sizes, from the clumsy, old-fashioned Dutch mill shown on Pl. LXI and the odd but effective homemade devices shown on Pl. XLII to the light, rapid-running steel mill of latest improved pattern shown on Pl. XLIII. An indefinite extension and multiplication of these is possible, as the power of the wind is practically limitless, and it can usually be depended upon, although sometimes failing at critical times. While each pump will furnish water for only one or two

acres, by increasing the number of pumps, farms of considerable size have been successfully tilled, as described on pages 265 to 270.

NORTH DAKOTA AND SOUTH DAKOTA.

The Dakotas extend from the fertile Red River Valley westerly across the Missouri River, the climate gradually becoming more and more arid until the Black Hills are reached. The country east of the Missouri River, consisting of extensive prairies and rolling uplands, is usually considered capable of raising a crop each season, although failure or diminished yield may occur at least one year in five. Irrigation is not largely practised, but it would be highly beneficial. The principal crop produced is wheat, the extremely deep, rich soil and level surface making possible the great so-called "bonanza" farms, where the apparently boundless ocean of waving grain extends in all directions to the horizon. On these great farms, where all the work is done by machinery, the cost of producing the crop is extremely small, and it is not considered possible or desirable to attempt irrigation; but on the small tracts, where diversified agriculture is practised and the long summer droughts bear heavily upon the plants, it has been found profitable to artificially apply water, particularly in the James River Valley, where there are a large number of artesian wells furnishing water to farms, as shown on Pl. LVIII, *A*.

West of the Missouri River the surface of the country has been deeply eroded, the soft horizontal beds being carved into the fantastic forms of the Bad Lands. Some grazing is found among these, and a little irrigation is practised at ranches along the streams, especially near their head waters, where they issue from the Black Hills. Here a considerable number of ditches have been taken out, and agriculture has been successful because of the excellent markets afforded at the near-by mines.

NEBRASKA.

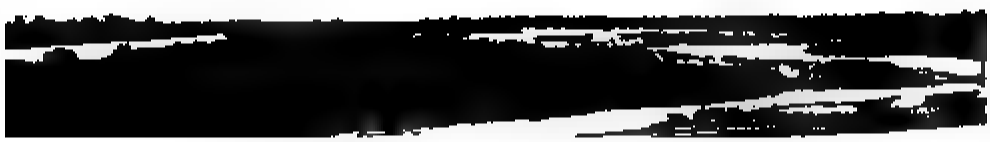
In this state irrigation is confined almost exclusively to lands along the North Platte River, extending from the Wyoming line easterly to the point where the south branch enters, forming the main Platte River. Farther east the climate becomes relatively humid, and, although a few irrigation systems have been constructed, the use of water has not been general, owing to the fact that in ordinary seasons crops are raised by dry farming.

The Platte and its principal tributaries are characterized by broad, sandy channels, whence has arisen the name. The view, Pl. LX, *A*, shows the North Platte at low water, with streams meandering across the sandy bottom in an interlacing network. At high water the stream spreads out, sometimes to great width, giving the appearance of an enormous volume of water, as shown by

Pl. LX, *B*. It is extremely shallow, however, and there is some foundation for the popular claim that the Platte is a mile wide and too shallow for navigation by a catfish.

There is almost always water in the North Platte and in the Platte, although it is occasionally reported that during droughts the channel is dry on the surface, the water coming from the west gradually disappearing in the broad stretch of sand and gravel, and percolating onward beneath the surface. The South Platte is usually dry during the summer for a hundred miles or more in Colorado, and on down to the junction of the channel with that of the North Platte; hence irrigation development along this stream has been limited to the use of flood waters during the early part of the year. South of the Platte, in the valleys of the Republican and other streams, and also in the northern part of the state, small areas are cultivated successfully by irrigation, and this method of agriculture is slowly extending as farmers become more skilful and appreciate the advantage of security from occasional crop failures.

A large part of the western end of Nebraska is covered with hills of shifting sand, and although the soil is extremely light and easily moved by the strong winds, yet, where moistened in the hollows between the hills, excellent crops have been produced. It is highly probable that the shifting of these hills can be prevented by planting shrubs or



A LOOKING DOWN NORTH PLATTE RIVER FROM THE NEBRASKA-WYOMING LINE.

B. HEAD GATES OF FARMERS AND MERCHANTS IRRIGATION COMPANY ON PLATTE RIVER, NEAR COZAD, NEBRASKA.

trees, and it has been proposed to cover this vast region more or less completely with forests, making the waste land valuable for the production of timber and rendering possible the utilization of the more level portions for farms.

KANSAS.

In this state the principal irrigated areas are along the Arkansas River, where the conditions are somewhat similar to those along the Platte. The broad, shallow channel is dry for a part of the year, but water is seeping beneath the surface of the valley lands as well as under the stream bed. The ditches, some of them built at large cost, can receive water only in times of flood; but by means of windmills small areas are irrigated, not only in the valleys, but even to a small extent on the adjacent upland plains. Artesian wells have been successfully constructed at a number of localities, notably at Meade in the southern part of the state, one of the small wells being shown on Pl. XXXVIII, *B*.

North of the Arkansas River and between it and the Republican in Nebraska are a number of creeks and rivers flowing eastward and receiving a supply of water during the dry season from perennial streams resulting from seepage, or, in other words, from the underflow reaching the surface. The volume of these is swelled in the early part of the year by local rains, but, taking the year as a whole, the dis-

charge is wonderfully uniform, because of the slow, gradual movement of the water from underground into the channels. Irrigation from these streams has been introduced, but, as noted on preceding pages, owing to the occasional success of crops without irrigation, progress has been slow and halting.

OKLAHOMA AND TEXAS.

In the recently settled territory of Oklahoma little has been accomplished, as the water supply in the western, arid end is limited and the pioneers, coming from humid regions, have as a rule not been familiar with the benefits of irrigation and have tried to get along without artificially applying water. This part of the territory, adjacent to Texas, is given up mainly to grazing, but a few ditches have been constructed for bringing water to alfalfa lands at the cattle ranches.

Throughout the great extent of high plains included within what is known as the Panhandle of Texas, irrigation is almost unknown. It is distinctly a cattle country, and water is regarded as of value principally for the use of cattle. Wells have been sunk on these high plains, and shallow tanks or ponds constructed at intervals of a few miles, to furnish convenient watering places, as shown on Pl. VII. The ranches are of enormous extent, the land having been sold or disposed of by the state of Texas in great tracts to cattlemen. There is a slow but gradual tendency to subdivide

these great tracts and to increase what is known as stock farming — that is, the carrying on of farming in connection with the ownership of small herds, thus multiplying the number of resident owners. Progress in this direction is extremely slow, and it will probably be many years before this vast tract of country will be subdivided so as to support a population at all commensurate with its possibilities.

On the extreme west, Texas extends far into the arid region, and on the border along the Rio Grande irrigation has been practised by the Mexicans living on both sides of the international boundary. From the earliest historical times the small communities have diverted water from the stream, tilled gardens, and raised fruit sufficient for their own needs. This condition of affairs has continued until the present time, some of the ancient ditches having been enlarged, and in a few instances, as at El Paso, large canals built to reclaim land and provide opportunities for new settlers. The flow of the Rio Grande is, however, extremely erratic, and, owing doubtless to diversions in Colorado and New Mexico, the channel of the river is frequently dry for months at a time.

In the western central part of the state, as at San Antonio and other towns settled by the Mexicans, irrigation has always been practised by them, and their example has been followed by their English-speaking neighbors, so that this method of

agriculture may be said to be widely, but not largely, in vogue. In the extreme east the cultivation of rice in the low Gulf counties has recently attained great importance through the flooding of low lands, to which water is brought largely by pumping.

DUTCH WINDMILL AT LAWRENCE, KANSAS.

CHAPTER XIII.

HUMID REGIONS.

EXPERIENCE has shown that irrigation is often advantageous even in localities where the climate is humid. If the rains came at regular intervals, moistening the soil whenever it became dry, there would be no need of the artificial application of water; but, unfortunately, it often happens that the precipitation for a month takes place in one or two large storms, which not only soak, but flood, the ground and, washing away the rich surface soil, may do more injury than good. The eastern half of the United States has been aptly termed the region of uncontrollable humidity, in contradistinction to the arid region, where, through systems of irrigation, the application of water to the soil can be exactly controlled.

Some of the heavier soils retain moisture for long periods, and the irregularities of rainfall do not noticeably affect vegetation, although somewhat retarding its growth and development. On sandy or pervious soils the alternations of wet and dry produce marked changes, and a drought of a few weeks' duration results in decided injury to

the crops. Thus it happens that in many parts of the humid region small irrigating systems have been built for occasional use. The investments in these may be regarded in the light of an insurance against the accidents of weather, which are so injurious to the farmer.

The most common and widespread form of irrigation is the ordinary practice of watering lawns and gardens. In this sense irrigation is habitually employed in every city and town throughout the United States, although not usually recognized under this name. There is no marked difference between the irrigation of suburban grass plots and gardens in the East, and that of large farms in the arid region, other than in size and completeness of the mechanical devices for conveying and distributing the water.

The almost universal practice of watering grass plots and vegetables testifies to the great value of the artificial application of water, even in the Eastern and Southern states, and the same systematic watering of orchards and fields would produce similar benefits. It is simply a question of cost relative to profits. In the arid region, where crops cannot be raised without water, the cost of bringing it to the fields has, by skill and experience, been reduced to the lowest possible amount. In the humid region, where the necessity has been less, invention and enterprise have not been stimulated to the same degree, and, while all the facilities for

irrigation exist, it has not been generally introduced on a large scale.

The practice of irrigation in arid regions has, to a certain extent, unconsciously prejudiced farmers in the humid regions against it, as they viewed it as something consequent upon desert conditions. It is, however, a method for improving the soil comparable to the application of fertilizers. Large expenses are incurred in purchasing enriching material to be added to the soil, and care is taken to save and apply barnyard manure to increase the yield of crops. The same amount of energy and expense devoted to the construction of irrigation works would doubtless yield even larger returns. Comparing irrigation also with drainage, it is noted that no hesitation is felt by the farmers of the humid East in digging ditches to remove surplus water from fertile bottom lands, but the reverse process, of bringing water to lands which would be productive if sufficiently moist, is a matter the importance of which has not been fully grasped by the agriculturist.

Water, as stated on pages 4 and 180, is the most important plant food, entering in great volume into their tissues, and being the vehicle by which other foods can be obtained in proper quantities. By regulating the supply of this, plant growth can be stimulated even in climates which seem moist, as is illustrated everywhere by watering lawns and kitchen gardens.

The supposedly great expense of bringing water to the fields has deterred many farmers from attempting irrigation. A little consideration and study, however, will show that farm ditches can often be built in humid lands at far less expense than in the arid region, because the water supply from running streams is larger and more widely distributed. The methods of constructing ditches have been described on pages 102 to 148, and it has been pointed out that irrigation systems on a rather large scale have been built by farmers or associations without employing any special engineering assistance or requiring capital. The work can be done by plough and scraper, aided by pick and shovel; and a man of ordinary skill in farm work, one who can lay out a drain or set an orchard in regular rows, can build an irrigating ditch.

The cost of irrigation in humid regions theoretically should be less than that in the West, owing to more widely distributed sources of water supply. As a rule it has been higher, because most of the devices have been experimental in character, or have been the result of the practice of what might be called fancy farming, where irrigation has been treated as a fad of the owner. The average first cost of bringing water to the land in the West, as ascertained by the 1890 census, was $8.15 per acre, and the average annual cost of maintenance was $1.07 per acre. The largest yearly expenditure is in California, as noted on pages 219 and 326. In

A. CLEAN SWEEP OF THE PRAIRIE FIRE

B. THE CARPET OF GRASS ON THE HIGH PLAINS.

the state of Connecticut 56 farms, with a total area under ditch of 471 acres, were reported as irrigated in 1899. The cost of the ditches, pipes, pumps, reservoirs, and other appliances for obtaining and conveying water to these farms was estimated at $16,113, — an average of $34.21 per acre irrigated, or about four times the cost in the arid region.

The value of various small fruits and market garden crops in the vicinity of large cities is estimated per acre as follows: — For strawberries and raspberries, from $200 to $400; asparagus, $100 to $200; onions, $150 to $300, and correspondingly with other vegetables. It is thus very easy for large losses to result from a slight deficiency in moisture. With water applied at the right time a crop may be worth $400 per acre, while the adjacent field, receiving a trifle less supply, yields only $100. The difference would repay the cost of one of the most expensive devices for obtaining a water supply.

The best results have often not been obtained because of the fear of getting the ground too wet. In the country of uncontrollable moisture, where rains are apt to occur any day, yet may not fall for weeks, there is always great uncertainty as to the weather, a condition which the farmer in the arid region is not required to meet. He knows that there will be no rain and probably no notable change in temperature for weeks. But in the humid region the farmer, seeing clouds gather, may conclude that, even if an irrigation system is

at hand, it will not be wise to turn water upon the fields. He usually hesitates until too late to secure the best results. If he does apply water, the land may be no sooner thoroughly wet than a heavy rain will occur, almost drowning out the plants. As a rule, however, on open or sandy soil it is difficult to apply too much water, and when the ground is thoroughly saturated after an irrigation the rain will merely flow off the surface or sink into the pervious soil.

Another obstacle to the development of irrigation in the East has been the possible interference with riparian rights. The laws of the humid East, borrowed from England, jealously guard the flowing waters, and as a rule confer extraordinary privileges upon millowners and others who make use of the stream for power. Any diversion of the flowing water for municipal purposes has been usually the subject of long controversy, and attempts to take out ditches for irrigation have often met with opposition on the part of owners of mill rights lower down the stream. It is therefore of great importance to have accurate measurements of the rivers in order to ascertain to what extent the diversion of water may affect water-power below, for it can probably be shown in many cases that the increased seepage in times of low water will compensate largely for the diversion of water, and may be so great as to increase the low-water discharge of late summer.

Owing to the fear of exactions by riparian owners, large irrigation systems have, as a rule, not been attempted in the East, but development has proceeded mainly along the line of using springs or of pumping water by wind power, steam, or gasolene engines. Devices of this kind are being rapidly improved and adapted to local conditions, the cost of procuring water being correspondingly reduced, so that it has been demonstrated that for five or ten acres a small pumping plant can be operated advantageously, the increased productiveness of the soil occasionally repaying, even in one season, all of the expense. This, of course, can be true only of the finer grades of fruits, berries, and market garden products. The pumping machines which have proved most successful are those designed for strength and simplicity, so as to require as little attention as possible.

A careful examination of the climatic records of almost any locality in the East shows that in each year the artificial application of water is needed for one crop or another. Sometimes the rains occur at the right times and in proper quantities for the success of orchards, but the fields suffer, or the small fruits and berries may have a diminished yield, while the gardens prosper. One or two years out of five nearly every crop is reduced through lack of moisture at a certain period of growth, so that, where diversified farming is practised and cultivation is intensive, a machine ar-

ranged for providing water can be operated to advantage for a portion of the farm at least. If, however, only a single farm crop is raised, the devices for procuring water are apt to fall into disuse, and by neglect become valueless when called into service after standing idle for two or three years. In short, irrigation is of greatest advantage where a variety of farming operations are practised.

It is not only the character of the crops which must be considered in introducing irrigation in humid climates, but also the quality of the soil. In arid regions all ground requires artificial watering. In humid regions, however, where irrigation is needed more to regulate the time of application than the quantity of water, the character of the soil must be more carefully considered, since some soils retain moisture for long periods. On such soils crops may flourish during a moderate drought, while on others the plants quickly wither unless water is continually applied. There is also a great difference in the quickness with which the soils and the crops together seem to respond to the application of water. With some vegetables, deeply cultivated, there does not seem to be any perceptible difference, while with others there is a most marked change following the systematic practice of irrigation.

The extent of irrigation in humid regions is attested by the numerous orchards and meadows

found by the census enumerators in nearly every state East as well as West. Even in New England there are small farms partly irrigated and partly drained, the distributing system having been in use for generations, and being regarded almost as the natural condition of things. The benefits are shown by the larger yield of hay and of fruit, repaying the trouble and expense of occasionally turning the water upon the ground.

Along the Atlantic coast from eastern New Jersey to Georgia are many areas of sandy soil, excellent for truck farming. Here early vegetables are raised for the New York and other markets. To force these to maturity and insure the largest yield, it has been found necessary to provide water, this being distributed usually through pipes from tanks, and occasionally through open furrows. The Chinese and Italian gardeners in the suburbs of New York and other Eastern cities, following the methods of their brothers on the Pacific Coast, irrigate successfully even in this humid region, and produce results which are envied by their native neighbors.

Irrigation is also practised along the Gulf coast, particularly in Louisiana and Texas, where the cultivation of rice has been found to be exceedingly profitable. Here water is obtained mainly by pumping, and great improvements have been made in machinery for this purpose. Water is also being stored for the rice fields, as it has been found that,

by excessive pumping in times of drought, the salt water from the Gulf has found its way inland up the bayous. To prevent this, extensive reservoirs have been constructed higher up on the rivers, in order that the flow may be reënforced in times of need.

Throughout the central Mississippi Valley, irrigation has been used to a less extent than along the Atlantic border, as the farms are large and the methods of cultivation are not so complete as in localities where the soil is less productive under natural conditions. Here, where nature has done so much, man has attempted little. It is recognized, however, that irrigation can be provided as an insurance against crop loss. During the time of a recent drought, when prayers were asked for rain, one sensible preacher refused, upon the ground that it was not proper to pray for rain when the opportunities for irrigating the fields had been systematically neglected. In other words, he would not invoke supernatural agencies to repair the consequences of man's shiftlessness.

CHAPTER XIV.

CONCLUSION.

IN summing up the whole matter of irrigation and its present condition, nothing more concise and direct can be given than a portion of President Roosevelt's first message to Congress, delivered December 3, 1901. In it he made the following statements: —

"In the arid region it is water, not land, which measures production. The western half of the United States would sustain a population greater than that of our whole country to-day if the waters that now run to waste were saved and used for irrigation. The forest and water problems are perhaps the most vital internal questions of the United States.

"The forests are natural reservoirs. By restraining the streams in flood and replenishing them in drought they make possible the use of waters otherwise wasted. They prevent the soil from washing, and so protect the storage reservoirs from filling up with silt. Forest conservation is therefore an essential condition of water conservation.

"The forests alone cannot, however, fully regulate and conserve the waters of the arid region. Great storage works are necessary to equalize the

flow of streams and to save the flood waters. Their construction has been conclusively shown to be an undertaking too vast for private effort. Nor can it be best accomplished by the individual states acting alone. Far-reaching interstate problems are involved; and the resources of single states would often be inadequate. It is properly a national function, at least in some of its features. It is as right for the national government to make the streams and rivers of the arid region useful by engineering works for water storage as to make useful the rivers and harbors of the humid region by engineering works of another kind. The storing of the floods in reservoirs at the head waters of our rivers is but an enlargement of our present policy of river control, under which levees are built on the lower reaches of the same streams.

"The government should construct and maintain these reservoirs as it does other public works. Where their purpose is to regulate the flow of streams, the water should be turned freely into the channels in the dry season to take the same course under the same laws as the natural flow.

"The reclamation of the unsettled arid public lands presents a different problem. Here it is not enough to regulate the flow of streams. The object of the government is to dispose of the land to settlers who will build homes upon it. To accomplish this object water must be brought within their reach.

"The pioneer settlers on the arid public domain chose their homes along streams from which they could themselves divert the water to reclaim their holdings. Such opportunities are practically gone. There remain, however, vast areas of public land which can be made available for homestead settlement, but only by reservoirs and main-line canals impracticable for private enterprise. These irrigation works should be built by the national government. The lands reclaimed by them should be reserved by the government for actual settlers, and the cost of construction should, so far as possible, be repaid by the land reclaimed. The distribution of the water, the division of the streams among irrigators, should be left to the settlers themselves, in conformity with state laws and without interference with those laws or with vested rights. The policy of the national government should be to aid irrigation in the several states and territories in such manner as will enable the people in the local communities to help themselves, and as will stimulate needed reforms in the state laws and regulations governing irrigation.

"The reclamation and settlement of the arid lands will enrich every portion of our country, just as the settlement of the Ohio and Mississippi valleys brought prosperity to the Atlantic states. The increased demand for manufactured articles will stimulate industrial production, while wider home markets and the trade of Asia will consume

the larger food supplies and effectually prevent Western competition with Eastern agriculture. Indeed, the products of irrigation will be consumed chiefly in upbuilding local centres of mining and other industries, which would otherwise not come into existence at all. Our people as a whole will profit, for successful home-making is but another name for the upbuilding of the nation.

"The necessary foundation has already been laid for the inauguration of the policy just described. It would be unwise to begin by doing too much, for a great deal will doubtless be learned, both as to what can and what cannot be safely attempted, by the early efforts, which must of necessity be partly experimental in character. At the very beginning the government should make clear, beyond shadow of doubt, its intention to pursue this policy on lines of the broadest public interest. No reservoir or canal should ever be built to satisfy selfish personal or local interests, but only in accordance with the advice of trained experts, after long investigation has shown the locality where all the conditions combine to make the work most needed and fraught with the greatest usefulness to the community as a whole. There should be no extravagance, and the believers in the need of irrigation will most benefit their cause by seeing to it that it is free from the least taint of excessive or reckless expenditure of the public moneys."

The Secretary of the Interior, Hon. Ethan Allen

Hitchcock, in his report to the President, dated November 21, 1901, also summed up the more important features of this great national undertaking, as follows:—

"In my report for 1900 attention was called to the importance of providing, through wise administration, for the creation of homes for millions of people upon the arid but fertile public lands. This matter is being given increased attention by the public press and by writers upon the subject.

"Briefly stated, the results of the examination of the extent to which arid lands can be reclaimed by irrigation show that, while one-third of the United States is still vacant, there are relatively few localities where homes can now be made. This is not because the soil is barren or infertile, but on account of the difficulty of securing an adequate water supply. There is water to be had, but this water is mainly in large rivers, from which it can be taken only by great structures, or the supply comes in sudden floods and cannot be utilized until great reservoirs have been built. It is impossible for a laboring man or an association of settlers to build these great works.

"The pioneer coming to the arid region found many small streams from which water could be taken out upon agricultural land. He was able through his own efforts to irrigate a small farm and to make a home. These easily available waters have been taken, and a man can no longer

secure a foothold, although there still remain 600,000,000 acres of vacant land. It is possible, by water storage and by building diversion works from great rivers, to bring water to points where such men can utilize it and can enjoy opportunities similar to those had by the earlier settlers. Unless this is done much of the country must remain barren, and thousands of men and women eager to become independent citizens must remain as wanderers or tenants of others.

"Enough work has been done by private capital to demonstrate the fact that water conservation and the diversion of large rivers is practicable, but, like many other works of great public importance, it cannot be made a source of profit. The works of reclamation already constructed have, as a rule, been unprofitable, and capitalists are no longer seeking opportunities for reclaiming desert land when the probabilities are against their receiving an adequate compensation for the risk and labor involved.

"The argument has been presented that if the government will not make it possible to bring water to these lands they should be turned over to the states; but the majority of citizens who have studied the subject are opposed to such action, on the ground that the vacant public lands are the heritage of the people of the United States and should be held for the creation of homes, and not made a subject of speculation, as has almost inva-

riably been the case with lands donated to the states. The whole trend of enlightened public sentiment is in favor of an expansion of industries and commerce internally through wise action by the national government rather than attempting to get rid of the duties and opportunities of ownership by giving away this valuable property.

"Two distinct conditions are to be clearly distinguished in the problem of water conservation for the development of the West. On the one hand, there are localities where the agricultural land along the rivers has been brought under irrigation and there is a demand for water to an extent far exceeding the supply, and where all of the flood water, though stored, would not suffice to satisfy the demands of the lands now partly tilled. The other contrasting condition is where there still remain vast bodies of public land for which water can be provided by means of reservoirs or by diversion from large rivers whose flow cannot be used. Here the construction of works of reclamation in no way affects lands now in private ownership. Between these two extremes are all varieties of intermediate conditions, but these may be arbitrarily classed with one or the other.

"In the first case reservoirs, if constructed, must be treated in the same way in which other public works having to do with rivers and harbors are managed. The water conserved should be used to increase the flow of the stream during the season

of drought, regulating the volume so that it can be utilized to the best advantage, according to the laws and customs prevailing in the locality. This is comparable to the conditions where the outlet of a harbor has been improved without reference to the benefits to the owners of the docks around the shores.

"Under the other condition, where there are unappropriated waters flowing to waste which can be brought within reach of public land, it is possible to make provisions such that the government can be reimbursed for its expenditure. The lands to be benefited by such works should be reserved for homestead entry only in small tracts, each being subject to the payment, before the title is finally passed, of a sum equivalent to the cost of storing or conserving the water, such payment to be made, if desired, in instalments extending over a number of years.

"Water should be brought to the point where the settlers can, with their own labor or by coöperation, construct ditches and laterals to reclaim the desert land. The conditions in this case would be comparable to opening a rich tract of land hitherto reserved. The moment the government throws down the desert barriers, or announces its purpose of so doing by making possible the obtaining of water, there will be an eager rush on the part of home seekers. With the requirement of actual settlement and cultivation, to be followed by the

payment of the cost of storing water, the speculative element will be eliminated, leaving the ground free to bona fide settlers.

"It is safe to predict from the recent struggles for homes upon the public domain that, if it should be determined that the San Carlos dam, for example, is to be built by the government, every acre of vacant land to be supplied with water would be immediately taken in small tracts by men who would not only cultivate the ground when water is had, but in the meantime would be available as laborers in the construction of the works, and would ultimately refund to the government the cost of the undertaking. In this manner thousands of the best class of citizens in the country would be permanently located in prosperous homes upon what is now a desert waste.

"It has been estimated that the western half of the United States would sustain a population as great as that of the whole country at present, if the waters now unutilized were saved and employed in irrigating the ground.

"The first step in water conservation has been taken by Congress in giving authority for setting aside great areas of wooded land, largely for the beneficial influence which they exert upon the water supply. This should be followed by the construction, within the forest reserves, and elsewhere when practicable, of substantial dams impounding flood and waste waters.

"Underground waters may be had in some localities where it is not practicable to irrigate the surface by means of stored water. The conditions favorable for artesian wells are believed to exist in a number of desert areas, and it is probable that important sources of supply can be had by artesian wells. The division of hydrography has begun the systematic study of some of these places, and has prepared maps showing the depth beneath the surface of the water-bearing rocks. Such maps are invaluable in the development of the country. These can be prepared for the edges of the artesian basins, where the rocks are partly upturned, but far out from the mountains it is necessary to sink test wells. If these are properly located after thorough study of all the surrounding conditions, it may be possible to settle the question of artesian supplies and definitely outline the underground condition for hundreds of square miles of public land. Only by obtaining such information can the value of this land and the practicability of settlement be made known. It is highly important, therefore, that a few such deep wells be drilled by the government upon desert land, for the purpose of demonstrating the possibility of reclamation. When it is proved that water can be had, even at considerable depths, settlement will follow.

"There is no function within the power of the government higher than that of making possible the creation of prosperous homes. In his speech

in Minneapolis, Mr. Roosevelt said: 'Throughout our history the success of the home-maker has been but another name for the upbuilding of the nation.' The remaining public lands are the heritage of the nation, and should be held for homes, being reserved for actual settlers under the homestead act. The area to be taken by any one man should be reduced so that when water has been conserved by the government the homestead shall, in certain parts of the country, be limited to eighty or even forty acres.

"The investigations of the government experts have shown that, for example, in Arizona, where high-class fruits are cultivated, a family of five can obtain a good living upon forty acres, or even twenty. In the colder parts of the arid region, where forage crops are largely raised, the area may be made one hundred and sixty acres.

"The water for irrigation should be distributed in conformity with the laws of the state and without interference with any vested rights which have already accrued.

"Where reservoirs or main-line canals are built by the national government to furnish water for the public lands, the administration should proceed in harmony with the state laws, as would be the case with any other large landowner — state and nation coöperating to accomplish a result of far-reaching benefit to both.

"The expansion of our interior trade and com-

merce, through the settlement of the arid lands and the increase of population in the West, would benefit every class and section of our country, in the same way that the settlement of the Ohio and Mississippi valleys has brought prosperity and wealth to the states east of the Alleghanies. The settlement of the vast arid region still farther to the west would benefit the whole eastern half of the United States by creating new home markets for Eastern merchants, Southern cotton growers, and all manufacturers. It would enormously increase local traffic, and would tend to relieve the congestion of our great centres of population, creating opportunities which would go far to allay social discontent. It would promote industrial stability by giving to every man who wanted it a home on the land. The rush for lands in Oklahoma testifies that there are multitudes of our people who will make great sacrifices to secure such homes.

"There need be no fear of competition of Western products with Eastern agriculture, since the Asiatic markets now opened will absorb the surplus of the Western farms. The character of these is also such that the staple crops of the East cannot now go to the remote West, nor those of the West come East, excepting in the case of semitropic and dried fruits.

"The investigations which have been carried on demonstrate that, looking at the matter from all

sides, *there is no one question now before the people of the United States of greater importance than the conservation of the water supply and the reclamation of the arid lands of the West, and their settlement by men who will actually build homes and create communities.* The appreciation of this condition is shown by the fact that both the great political parties inserted in their platforms articles calling attention to the necessity of national aid for the creation of homes on the public domain.

"In view of the facts above noted it is imperative to adopt at an early date a definite policy leading to the best use of the vacant public lands. It is recommended that construction be at once begun upon certain property where the conditions are known to be such that beneficial results will follow."

The President and Secretary do not ask the government to do something which might be better done by private enterprise. The latter has already built irrigation works sufficient to utilize nearly the whole available flow of the streams in the arid regions during the irrigation season. Further progress in irrigation can come only through the storage of flood waters in reservoirs; and nearly all of this work is absolutely impossible without government aid. Remembering the great productiveness of irrigated lands, and that farming with irrigation is almost always intensive farming, the estimate that these reclaimed lands will provide food and homes

for a population "greater than that of our whole country to-day" does not seem extravagant.

In comparison with such a possible development every other project or public work which the government is asked to undertake seems indeed insignificant. The dead and profitless deserts need only the magic touch of water to make arable lands that will afford farms and homes for the surplus people of our overcrowded Eastern cities, and for that endless procession of home-seekers filing through Castle Garden.

The national government, the owner of these arid lands, is the only power competent to carry this mighty enterprise to a successful conclusion, to divide the reclaimed lands into small farms for actual settlers and home-builders only, and to provide water for the settlers at a price sufficient merely to reimburse the cost of the work.

When the plans for irrigation suggested by President Roosevelt and Secretary Hitchcock are carried out, every section of this country will be benefited. The East and Middle West will find in that regenerated empire a market for machinery and manufactured products of every description; the South will find ready sale for the fabrics of her cotton looms; while the farmers of the reclaimed regions will send the cereal products of their acres across the Pacific to the swarming millions of the Orient. Viewed from every standpoint, the national irrigation movement is full of promise to the nation.

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